Volume XLII August 1947 Number 5

Economic Geology

and the

Bulletin of the Society of Economic Geologists

LIBRARY SEP 9 194

CONTENTS

Geology of the Red Rose Tungsten Mine, Hazelton, British Columbia ..... *John S. Stevenson* 433

Sangdong Tungsten Deposit, Korea ..... *M. R. Klepper* 465

The Metalliferous Geochemical Zones of Australia ..... *E. Sherbon Hills* 478

An Eolian Dam Near Tucumcari, New Mexico ..... *E. Dobrovolny and R. C. Townsend* 492

Reviews:

Geology and Ground-Water Resources of the Island of Hawaii (Stearns and MacDonald) ..... *D. J. Cederstrom* 498

Tungsten, Its History, Geology, Ore-Dressing, Metallurgy, Chemistry, Analysis, Applications and Economics (Li and Wang) 500

A Yanqui in Patagonia (Willis) 501

Texas Mineral Resources 501

Books Received ..... *Alan T. Broderick* 501

Society of Economic Geologists:

Report of the General Committee on Research ..... *C. H. Behre, Jr.* 505

Report of the Committee on Research on Coal ..... *G. H. Cady* 509

Scientific Notes and News 513

PUBLISHED SEMI-QUARTERLY

Five Dollars a Year, One Dollar a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Printed by Lancaster Press, Inc., Prince and Lemon Streets, Lancaster, Pa.

Entered as second-class matter, March 30, 1906, at the Post Office at Lancaster, Pa., under the Act of Congress of March 3, 1879

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

Manuscripts for publication should be sent to the Editor, **ALAN M. BATEMAN, at Yale University, Yale Station, New Haven, Conn.** It is requested that contributors exercise care in writing *scientific* and *proper names.* References to other publications should be in accordance with the forms used in the pages of this journal. The manuscript should be typewritten with double space lines and must be preceded by *a brief abstract.* Galley proof will be sent authors only where a request to this effect accompanies the manuscript, or when, in the editor's opinion, the subject matter is such as will require correction by the author.

Reviews should conform to the journal usage. Review Committee: The Editor, C. H. Behre, L. C. Graton, J. T. Singewald, Jr., J. Gilluly, A. F. Buddington, W. H. Newhouse.

Books and Pamphlets for review should be sent to the Editor.

Reprints. Contributors desiring reprints of their papers may obtain them by filling out the order slip which will be attached to the galley proof when it is sent to the author. Provided the order slip is received by the editor, *with the return of the proof,* 50 reprints without covers will be furnished without charge. Reprints of discussions and informal communications are not furnished free of charge except when they exceed four pages in length when 50 will be supplied without charge. Reprints of reviews are not supplied. Additional reprints will be furnished at approximately the rates given in the table below when ordered *in advance of publication.* The rates apply only to plain text, with line engravings. Papers containing folded maps or plates will be more expensive.

The following rates *do not* include free carriage. *Postage or express must be paid by the author.*

	4 pp.	8 pp.	12 pp.	16 pp.	20 pp.	24 pp.	28 pp.	32 pp.
50 copies	$2.75	$4.30	$6.50	$7.00	$9.00	$10.25	$11.75	$12.50
100 "	3.50	5.25	7.75	8.50	10.75	12.50	14.50	15.50
200 "	4.50	6.75	10.25	11.50	14.25	17.00	20.00	21.50

Standard covers are of the same style of type and paper as the cover of the journal, and bear the title of the article and name of its author. Special printing on cover is charged for at the cost of composition. Plates are $2.00 for the first 50 if printed on one side, and 1½ cents for additional ones; printed on both sides, $3.00 for the first 50, and 2¼ cents for additional ones.

Single copies of reprints (without covers) of many of the articles published in volumes issued since 1926 (Vol. XXI) are available at the following prices, upon application to the **Business** Editor, at Urbana, Illinois.

1-4 pp. 15c	5-8 pp. 20c	9-12 pp. 25c	13-20 pp. 30c	21-28 pp. 35c
29-36 pp. 40c	37-44 pp. 45c	45-52 pp. 50c	53-60 pp. 55c	61-68 pp. 60c

If illustrated by plates, add 3c for each plate if printed on one side, and 5c if printed on both sides.

Subscriptions. The price of the journal to subscribers in the United States and its dependencies is $1.00 for a single copy, or $5.00 a year for eight numbers. To subscribers in Canada, Cuba, Mexico, Spain, and countries in Central and South America, except Dutch and French Guiana, the annual rate is $5.30; to other countries, $5.75.

Forwarding. Subscribers wishing their journal to be forwarded to a new address should leave postage for that purpose with the Postmaster at their old address.

Missing numbers will be replaced without charge if claim is made within four weeks after the date of issue of the following number, provided that the neglect to receive them is not due to neglect to arrange for their forwarding.

Remittances should be made payable to the **ECONOMIC GEOLOGY PUBLISHING COMPANY,** and should be mailed to **M. M. LEIGHTON,** Business Manager, Urbana, Illinois, to whom also all **Business Communications** should be addressed.

Foreign Agents. Geo. Allen and Unwin, Ltd., No. 40 Museum St., London, W. C. 1, **British Agents.**

Indexed in the Industrial Art Series.

LANCASTER PRESS, INC., LANCASTER, PA.

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF ECONOMIC GEOLOGISTS

EDITOR: ALAN MARA BATEMAN
Yale University, New Haven, Connecticut

BUSINESS EDITOR: MORRIS M. LEIGHTON
Illinois Geological Survey, Urbana, Illinois

ASSOCIATE EDITORS

CHARLES KENNETH LEITH
University of Wisconsin, Madison, Wis.

D. F. HEWETT
U. S. Geological Survey, Washington, D. C.

C. N. FENNER
Geophysical Laboratory, Washington, D. C.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
U. S. Geological Survey, Washington, D. C.

HEINRICH RIES
Cornell University, Ithaca, N. Y.

OSCAR E. MEINZER
U. S. Geological Survey, Washington, D. C.

L. C. GRATON
Harvard University, Cambridge, Mass.

E. C. ANDREWS
Sydney, Australia

E. S. MOORE
University of Toronto, Toronto, Can.

A. I. LEVORSEN
Department of Geology, Stanford University, Calif.

PER GEIJER
Geological Survey of Sweden, Stockholm, Sweden

P. F. FOURMARIER
Liége University, Liége, Belgium

ALEX. L. DU TOIT
Capetown, South Africa

M. J. S. KRISHNAN
Geological Survey, Calcutta, India

DJALMA GUIMARÀES
Instituto de Tecnologia Industrial
Belo Horizonte, Minas Gerais, Brazil

A SEMI-QUARTERLY JOURNAL PUBLISHED BY

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1947

GEORGE H. ASHLEY .....*President*
OLAF N. ROVE .....*Secretary*
Annandale Road, R. F. D. No. 1
Falls Church, Va.

G. M. FOWLER .....*Vice-Pres.*
J. T. SINGEWALD, JR. .....*Treasurer*
Johns Hopkins Univ., Baltimore, Md.

Councilors

1947	*1948*	*1949*
FRANCIS CAMERON	V. T. STRINGFIELD	ERNEST F. BEAN
GEORGE M. FOWLER	FRANK R. CLARK	GILBERT H. CADY
THOMAS G. MOORE	JOSEPH L. GILLSON	J. E. HAWLEY

Regional Vice-Presidents

DAVID WILLIAMS .....London, England .....*For Europe*
P. K. GHOSH .....Calcutta, India .....*For Asia*
HENDRICK JAN SCHUILING .Jadotville, Belgian Congo .....*For Africa*
EZEQUIEL ORDONEZ .....Mexico, D. F., Mexico .....*For North America*
JORGE A. BROGGI .....Lima, Peru .....*For South America*
ROBERT L. JACK .....Melbourne, Australia .....*For Australia*

Executive Committee

GEORGE H. ASHLEY, *Chairman* — GEORGE M. FOWLER — T. M. BRODERICK
OLAF N. ROVE — J. T. SINGEWALD, JR. — W. O HOTCHKISS

Finance Committee

W. O. HOTCHKISS, *Chairman* — J. T. SINGEWALD, JR. — RAYMOND FRANK BAKER
ALLEN W. PINGER

Program Committee

MORLEY E. WILSON, *Chairman* — ROBERT A. LAURENCE — PARKER TRASK
CYRIL W. KNIGHT — M. M. LEIGHTON

Committee on Publications

H. E. MCKINSTRY, *Chairman* — C. S. ROSS — E. F. BEAN

Nominating Committee

THOMAS G. MOORE, *Chairman* — H. R. ALDRICH — D. H. MCLAUGHLIN

Membership Committee

DONALD M. DAVIDSON, *Chairman* — H. E. CULVER — S. W. LOHMAN
H. S. MCQUEEN — WM. F. JAMES — DAVID ST. CLAIR

LIBRARY
SEP 9 1947

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. XLII AUGUST, 1947 No. 5

GEOLOGY OF THE RED ROSE TUNGSTEN MINE, HAZELTON, BRITISH COLUMBIA.*

JOHN S. STEVENSON.

CONTENTS.

	PAGE
Abstract	434
Introduction	434
General Geology	437
Volcanics	437
Intrusives	439
Thermal Metamorphism	442
Structure	442
Scheelite Vein	444
Form	444
Texture	444
Mineralogy	444
Oxidation	450
Wall-rock Alteration	451
Structural Analysis of the Vein-shear and Branch Shears	452
Localization of Ore	453
Origin	454
Spectro-chemical Analyses of Minerals and Rocks	454
Minerals	460
Elements Detected	460
Comparison of Mineral Species	460
Comparison of Vein-minerals with Rock-minerals	461
Comparison of Early Vein-minerals with Late Vein-minerals	461
Rocks	461
Hornfelsed Tuff	462
Diorite	462
Andesite Porphyry and Feldspar Porphyry	462
Comparison of Rock Types	462
Summary and Conclusions	463
Acknowledgments	464

* Presented at the annual meeting, Geological Society of America, Chicago, Ill., December 27, 1946. Published by permission of the Chief Mining Engineer, B. C. Department of Mines.

ABSTRACT.

The Red Rose mine was British Columbia's largest producer of tungsten during World War II. Scheelite occurs in a shear-zone that cuts Mesozoic Coast Range intrusives and hornfelsed tuff within 750 feet of the Rocher Déboulé batholith. The minerals include scheelite, some ferberite, and, in order of abundance: quartz, orthoclase, oligoclase, apatite, biotite, hornblende, chlorite, ankeritic carbonate, chalcopyrite, and molybdenite. Cobaltian arsenopyrite, pyrrhotite, chalcopyrite, quartz, and tourmaline occur in the shear beyond the scheelite.

The scheelite ore occurs in two shoots where the shear cuts a 400-foot diorite sill but is not found where the shear cuts hornfelsed tuff. The stress diagram of the vein-shear and related breaks shows that the two ore shoots pitch in the same direction as the pitch of the intersection of potential tension openings with the vein.

Spectro-chemical analyses of 28 specimens of wall-rock and nearby rocks and of 14 specimens of vein- and rock-minerals showed variations of the trace elements in groups in which the range in atomic radii was within the 15 percent limit allowed by Goldschmidt in his rule for isomorphism of elements. Tungsten was absent in all the rock analyses; apparently it did not wander as a trace element into the wall-rocks.

The lenticular form, coarse to pegmatitic texture, and mineralogy of the tungsten vein, imply formation at high pressure and temperature (hypothermal). As a producing property, the Red Rose is unique in a class of scheelite deposits that does not ordinarily include commercial deposits of tungsten.

INTRODUCTION.

THE Red Rose mine is in northern British Columbia, 12 miles in an air-line southerly from the town of Hazelton (Fig. 1). The workings (Fig. 2), between elevations of 5,650 and 6,400 feet, are above timberline on the western slopes of the Rocher Déboulé mountains. These mountains are 50 miles northeast of the main Coast Range.

The property was staked in 1913 and the early work was done on outcrops of the vein where it carried small amounts of copper, gold, and silver. These workings have been described by Kindle.[1] It was not until 1923 that scheelite was found in outcrops of the same vein 700 feet above the copper-gold-silver showings. However, little work was done on these until the summer of 1940 when the Consolidated Mining and Smelting Co., Ltd., drilled 12 diamond-drill holes, ranging from 70 to 250 feet in length, that cut the vein from 80 to 325 feet below the outcrop. Shortly afterwards, this company started underground work, built a 75-ton mill, and started milling in October 1942. Milling continued until November 1943, when the property was closed down because of lack of markets and shortage of labor. During this period "600 tons of high—(73.8%) and low—(14%) grade concentrates, (344 tons of WO_3) were shipped, the average grade of the ore treated being 1.64% WO_3," [2] making the mine the largest producer of tungsten in the province during World War II.

[1] Kindle, E. D., Mineral resources, Hazelton and Smithers areas, Cassiar and Coast districts, B. C., Geol. Survey of Canada, Mem. 223, p. 57, 1940.

[2] Wilmot, V. Eardley, Tungsten in 1944, p. 2, in the Canadian Mineral Industry in 1944. Dept. of Mines and Resources, Ottawa, Canada, No. 815, 1945.

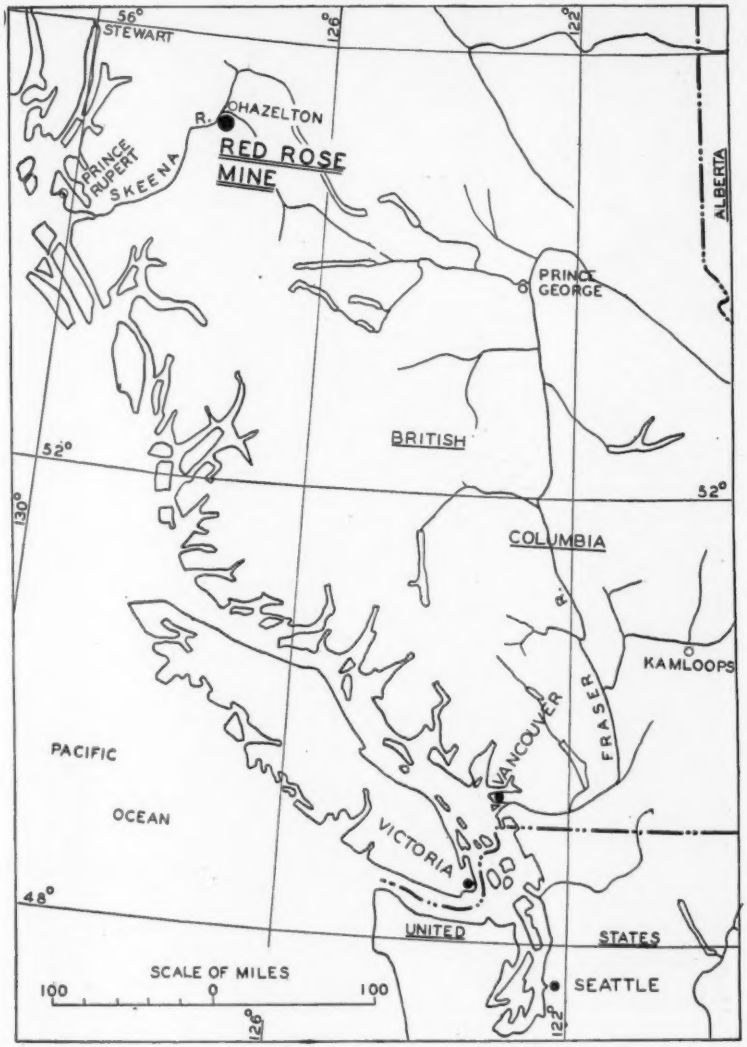


FIG. 1. Key map showing location of the Red Rose mine.

FIG. 2. Red Rose mine-camp. The covered skip-way leads to the portals of Nos. 6 and 3 adits, and the upper terminal of the tram-way to the mill is at the portal of No. 6 adit. The arrow points to the outcrop of the scheelite vein.

The writer examined the property in 1939 and 1942 and in 1943 published a short report on it.[3] He examined it in greater detail in 1943, when the more extensive underground workings permitted better correlation of the surface and underground geology than had been possible on previous examinations.

GENERAL GEOLOGY.

The rocks on the property include hornfelsed tuff, andesite porphyry, diorite, feldspar porphyry and granodiorite. The distribution of these rocks is shown in Fig. 3. The geologic setting of the property in the Hazelton area is shown on the Hazelton Sheet, Preliminary Map 44–24 of the Geological Survey of Canada. On this map the intrusive rocks near the Red Rose are shown as Upper Cretaceous or later in age and the nearby intruded rocks as Upper Jurassic or Lower Cretaceous.

Hornfelsed Tuff.—The hornfelsed tuff is a massive, very fine-grained rock that breaks with a sharp conchoidal fracture. It is dark brownish-grey in color, definitely brownish because of an abundance of fine biotite. The rock consists of 6- to 12-inch beds of massive, brown tuff separated by ⅛- to ¼-inch partings of shaly, black argillaceous material. The finely laminated bedding characteristic of otherwise massive tuff may be seen only in well-weathered material where weathering has differentially etched the beds. Because of the severe action of snow and ice, and the frequency of rock slides, the outcrops on the hillside near the workings are of freshly broken rock and only slightly weathered. However, the writer did find some material in old talus-slides sufficiently well-weathered to bring out the finely laminated bedding characteristic of tuff.

In the absence of banding either in outcrops or underground, the structure of the tuff was determined from the attitude of shaly partings intercalated between the more blocky tuff. In general these shaly partings strike N.N.E. and dip 45°–60° N.W.

Under the microscope the hornfelsed tuff is seen to consist of unoriented flakes and clusters of biotite in a fine-grained mosaic of quartz and untwinned oligoclase. Small amounts of widely scattered sericite comprise the only alteration product. Tourmaline that is probably hydrothermal occurs in vein-like clusters of grains.

The original character of the rock near the workings has been entirely destroyed by recrystallization. However, about 1,500 feet from the workings, it grades into finely laminated, argillaceous rock that, because of the fineness and extreme angularity of the quartz grains, is thought to be an argillaceous tuff. The recrystallized rock near the workings is therefore referred to as a hornfelsed tuff.

Andesite Porphyry.—Andesite porphyry outcrops on the hillside northeast and southeast of the workings but it is not found underground. It occurs as tabular bodies conformable with the sediments, but because of folding between diorite sills, and variations in thickness of the bodies, the outcrops are very irregular in shape (Fig. 3). Although flow structures have not been identi-

[3] Stevenson, J. S., Tungsten deposits of British Columbia. B. C. Department of Mines, Bull. 10 (Revised), pp. 60–71, 1943.

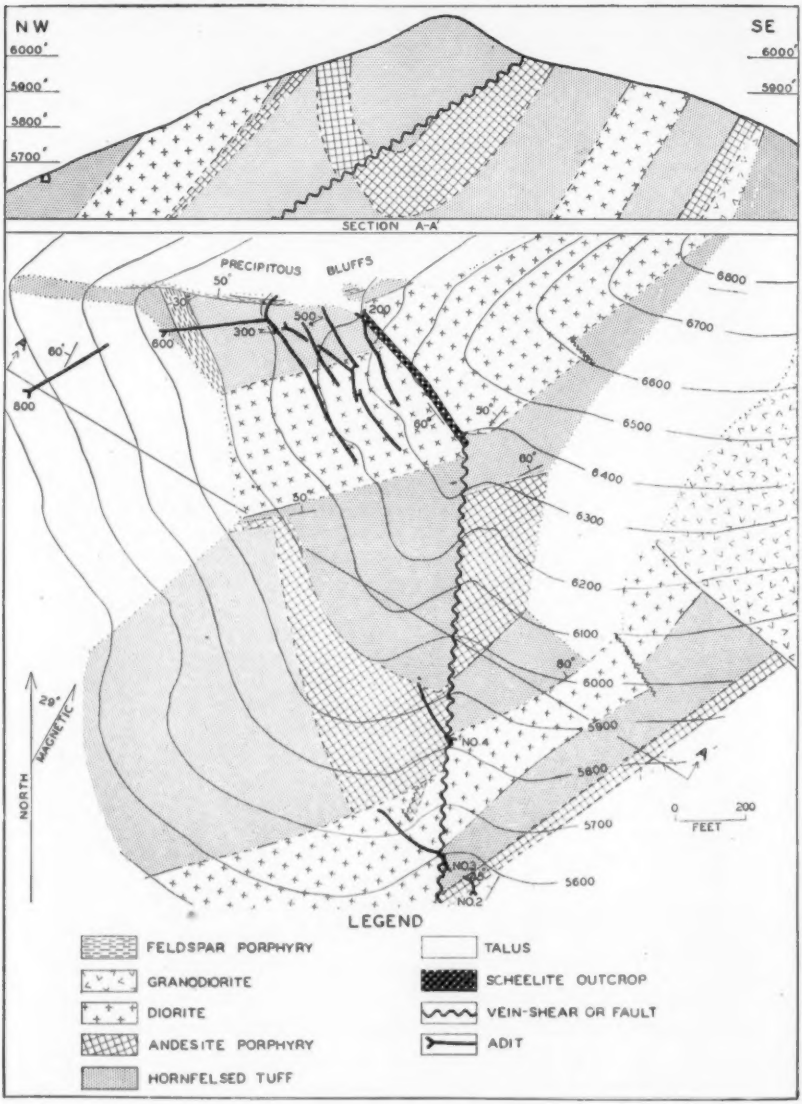


FIG. 3. Geological map and structure section.

fied, a markedly porphyritic texture and the lack of any intrusive features suggest that the andesite porphyry is a flow-rock, interbedded with the hornfelsed tuff.

The andesite porphyry is dark brownish-grey in color, massive in structure and is strikingly porphyritic in texture. Under the microscope it is seen to consist of andesine (Ab_{50}) phenocrysts, measuring 1 mm by 0.8 mm, and a few, smaller, relict areas of light green hornblende phenocrysts, set in a fine-grained ground-mass of andesine and biotite. The plagioclase laths in the ground-mass range from 0.7 by 0.2 mm to 0.1 by 0.03 mm; the biotite is of a similar size and occurs as scattered flakes or clusters that are pseudomorphic after hornblende crystals. A small amount of hornblende is still present in much of the biotite. The accessory minerals are quartz and apatite and the secondary minerals, sericite and leucoxene. The mode of a typical specimen of andesite porphyry is given in Table 1, column 1.

TABLE 1.

MODAL ANALYSES OF ROCKS.

	1	2	3	4
	percent	percent	percent	percent
Quartz	8	3	5.4	20
Orthoclase	—	—	—	19
Plagioclase	46	60	74.5	47
Apatite	—	0.4	—	trace
Biotite	42	12	—	3
Hornblende	3	24	19.1	9
Ilmenite-Magnetite	—	1.6	1.8	2

1. Andesite porphyry; phenocrysts 62 percent and groundmass 38 percent.
2. Diorite.
3. Feldspar porphyry dyke; phenocrysts 40 percent and groundmass 17 percent.
4. Granodiorite.

Diorite.—Diorite is found in two large sills, an upper and lower (Fig. 3) which strike N. 30°–45° E. and dip 50°–60° N.W. Although the upper sill outcrops over widths which range from 300 to 500 feet, it has a true width of only about 275 feet. The narrower, lower sill, has a true width of about 175 feet. The upper sill is important because the tungsten ore-body has been found only in this sill and neither in the adjacent hornfelsed tuff nor in the lower sill.

The diorite is massive in structure, greenish grey in color and possesses a fine, even-grained texture. Under the microscope it is seen to consist of clusters of brown biotite and green hornblende in a felted mass of andesine laths. The plagioclase crystals range in size from 0.07 by 0.3 mm to 0.7 by 2 mm; the hornblende crystals are uniformly about 0.4 by 0.6 mm and the biotite crystals generally 0.1 to 0.05 mm. The plagioclase is andesine of composition Ab_{55}. The hornblende has alpha index 1.644 and gamma index 1.673, an extinction angle against Z of 20°; and a 2 V of 72° (as measured on a Universal Stage). It is therefore termed "ordinary hornblende." The biotite has a gamma index 1.667.

The accessory minerals include quartz, apatite, zircon, sphene and iron oxides. Zircon is found surrounded by pleochroic halos in the biotite and usually only remnants are present, but occasionally whole, perfectly-shaped crystals are found. The secondary minerals include leucoxene, sericite and carbonate.

The mode of typical material is shown in Table 1, column 2 and a chemical analysis and calculated norm are given in column 1 of Tables 2 and 3. Mineralogically and chemically the rock is a typical diorite, very similar to diorites found elsewhere in the western Cordillera.

TABLE 2.

CHEMICAL ANALYSES OF DIORITE AND GRANODIORITE; RED ROSE GRANODIORITE COMPARED WITH ALASKA AND CALIFORNIA GRANODIORITES.

(Modes of Red Rose diorite and granodiorite are given in Table 1.)

	1	2	3	4	5
SiO_2	53.74	64.58	63.85	64.87	64.18
Al_2O_3	17.65	15.74	15.84	16.26	17.02
Fe_2O_3	0.27	1.67	1.91	1.51	0.79
FeO	6.98	2.43	2.75	2.89	2.43
MgO	4.69	1.97	2.07	1.72	1.69
CaO	8.18	4.48	4.76	4.72	4.32
Na_2O	3.69	3.73	3.29	3.82	3.87
K_2O	1.66	2.81	3.08	3.30	2.84
H_2O (−105°)	0.11	0.10	.28	0.00	0.03
H_2O (+105°)	1.12	1.49	1.65	0.28	0.85
TiO_2	1.25	0.57	.58	0.70	0.53
P_2O_5	0.33	0.20	.13	0.19	0.08
MnO	0.096	0.056	.07	—	0.06
BaO	0.09	0.10	.06	—	0.13
CO_2	—	—	—	—	0.21
SO_3	—	—	—	—	0.91

1. Diorite, Red Rose. G. C. B. Cave, analyst.
2. Granodiorite, Red Rose. G. C. B. Cave, analyst.
3. Granodiorite, Grass Valley, California. W. F. Hillebrand, analyst. Lindgren, W., Granodiorite and other intermediate rocks. Am. Jour. Sci., 4th Series, vol. 9, p. 273, 1900. Norm as calculated by Washington, H. S., Chemical analyses of igneous rocks. U. S. Geol. Survey Prof. Paper 99, p. 361, 1917.
4. Granodiorite, core of Coast Range Batholith. J. G. Fairchild, analyst. Buddington, A. F., Coast range intrusives of southeastern Alaska. Jour. Geology, vol. 35, p. 245, 1927.
5. Granodiorite, Mill City, Nevada. F. A. Gonyer, analyst. Kerr, P. F., Tungsten mineralization in the United States. Geol. Soc. America, Mem. 15, p. 24, 1946.

Feldspar Porphyry.—Several dikes of light colored feldspar porphyry, ranging from 1 foot to 50 feet thick, are found both underground and on the surface. The feldspar porphyry is a massive, light grey rock consisting of feldspar phenocrysts set in a medium-grained, grey ground-mass. This rock lacks the greenish color and the even-grained texture of the diorite and although porphyritic, lacks the contrasting fine-grained ground-mass and dark brownish color of the andesite porphyry.

Under the microscope the feldspar porphyry is seen to consist of feldspar phenocrysts from 2 by 1 mm to 5 by 1 mm set in a medium-grained groundmass of plagioclase, the grain size of which ranges from 0.1 to 0.6 mm. Both

TABLE 3.

NORMS CALCULATED FROM ANALYSES IN TABLE 2.

Normative Minerals	1	2	3	4	5
Quartz	2.58	20.46	19.44	16.98	18.78
Orthoclase	10.01	16.68	18.35	19.46	16.68
Albite	30.92	31.44	27.77	32.49	33.01
Anorthite	26.69	17.79	19.18	17.24	19.46
Diopside	10.95	3.15	2.94		—
Hypersthene	16.86	5.63	6.54	9.53	6.44
Olivine	—	—	—		—
Titanite	—	—	—	1.78	—
Ilmenite	2.28	1.06	1.06	—	0.91
Magnetite	0.46	2.55	2.78	2.09	1.16
Apatite	0.34	0.34	0.34	0.45	0.34

Column numbers refer to same rocks and references as in Table 2.

the phenocryst plagioclase and the ground-mass plagioclase are andesine of composition Ab_{60}. In addition to andesine, small amounts of quartz, green hornblende, biotite with included zircon, iron oxides, sphene and leucoxene are found in the ground-mass. Hydrothermal apatite is found as blebs and short veinlets in the feldspar porphyry where cut by the tungsten vein. The mode of typical material is shown in Table 1, column 3.

Granodiorite.—A large area of granodiorite is found on the mountain side east of the workings where it forms part of a larger area that extends for about 2 miles farther east. Granodiorite is also found northwest across Armagosa Creek beyond the area mapped by the writer. The granodiorite body east of the workings appears to plunge 25°–50° W. towards the body across Armagosa Creek, and it is probable that this body connects with that across Armagosa Creek at no great depth below the Red Rose workings.

The granodiorite is a massive, medium-grained rock, light grey in color and speckled with glistening black biotite and hornblende. Under the microscope it is seen to be hypidiomorphic in texture and to consist mainly of quartz, andesine (Ab_{65}), orthoclase, hornblende and biotite. Accessory minerals include apatite, zircon, titanite and iron oxides. Secondary constituents include leucoxene, sericite and carbonate. The general grain size of the rock ranges from 0.5 to 1.0 mm.

The mode of typical material is given in Table 1, column 4 and a chemical analysis and calculated norm are given in column 2 of Tables 2 and 3. The rock would be called a biotite-bearing hornblende-granodiorite, according to Johannsen,[4] or simply a granodiorite, according to Lindgren.[5] The chemical analyses and norms of granodiorite from California, southeastern Alaska and Nevada are also given in Tables 2 and 3 for comparison. The similarity of the Red Rose granodiorite with other Cordilleran granodiorites is very striking, and indicates the widespread occurrence of this type of rock in the western

[4] Johannsen, Albert, A descriptive petrography of the igneous rocks. Univ. of Chicago Press, vol. I, p. 149, 1932.

[5] Lindgren, W., Granodiorite and other intermediate rocks. Am. Jour. Sci., 4th Series, vol. 9, p. 279, 1900.

Cordillera. The similarity of the Red Rose granodiorite to the granodiorite (column 5, Table 2) associated with the contact metamorphic scheelite deposits of Mill City, Nevada, is in support of Kerr's observation [6] that granodiorite and granite are the two types of intrusives most commonly associated with tungsten mineralization.

Spessartite Dike.—The youngest rock seen is a spessartite dike, a strike N.W. and dip 65° S.W. and from a few inches to 2 feet wide, that is found underground towards the southeastern end of the 200, 300 and 600 levels. The dike cuts across the vein at a small angle, but does not noticeably displace it. The rock consists of a felted mass of basaltic hornblende and andesine, with a little chlorite and epidote.

Thermal Metamorphism.—Thermal metamorphism by the nearby granodiorite has produced mineralogical and textural changes in the intruded rocks, particularly in the hornfelsed tuff, for a distance up to 2,000 feet from the granodiorite.

The diorite and andesite porphyry contain very little primary hornblende; most of it has recrystallized to new hornblende or has altered to biotite. Recrystallization of the large crystals of primary hornblende to smaller crystals of new hornblende takes place outwards from fractures in the original crystal, and eventually results in a pseudomorph that consists of a felted mass of small hornblende crystals. In addition to pseudomorphic replacement, some of the hornblende has migrated in solution from the original crystal and recrystallized as small crystals of hornblende either between crystals of plagioclase or along fractures with individual crystals of plagioclase.

Secondary biotite after hornblende is found in the thermally metamorphosed rocks where it is always inversely proportioned to the hornblende. Some biotite has formed as rims around relict crystals of primary hornblende and some has formed as clusters of flakes pseudomorphic after the small crystals of secondary hornblende. Some has migrated in solution from the site of the hornblende crystals and recrystallized as flakes widely scattered through the rock. In this process biotite is dispersed from the larger clusters first as trailers of small crystals, some of which may rim or cut nearby plagioclase crystals, and then as widely scattered small clusters or single, unoriented flakes that in places impart a decussate texture to the rock.

In the hornfelsed tuff the original felsic and ferromagnesian minerals have recrystallized to a mosaic of quartz, untwinned plagioclase and biotite flakes.

The hornfels texture which is so marked in the hornfelsed tuff and is spottily developed in other rocks older than the granodiorite, suggests recrystallization at elevated temperatures in a stress-free environment. This metamorphism appears to have been caused by the heat of the granodiorite intrusion.

Structure.—The hornfelsed tuff, andesite porphyry and diorite sills strike N.E. and in general dip N.W. However, this simple structure is complicated by a drag-fold in the andesite porphyry and hornfelsed tuff between the two diorite sills. This is shown in the structure section along the line A–A′ in Fig. 3 and in Fig. 4.

[6] Kerr, P. F., Tungsten mineralization in the United States. Geol. Soc., America, Mem. 15, p. 23, 1946.

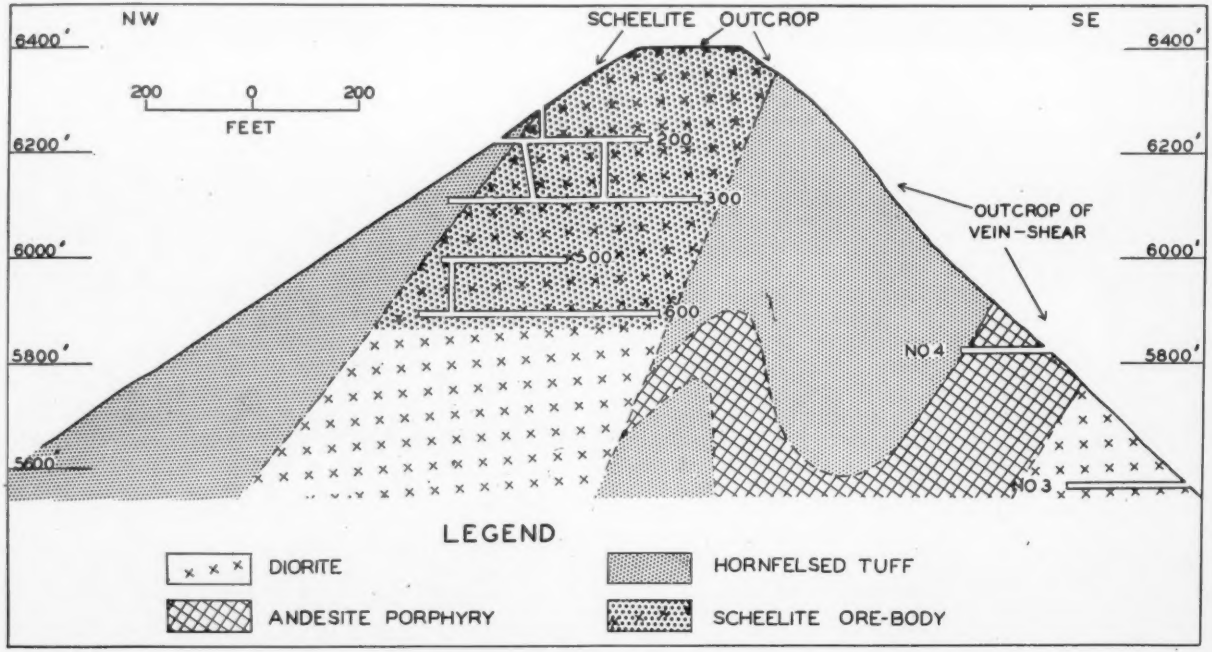


FIG. 4. Longitudinal section of the vein-shear showing scheelite ore-body and geology in hanging-wall of shear.

SCHEELITE VEIN.

The main tungsten mineral is scheelite, found in a vein that occupies a shear-zone, strike N. 30° W. and dip 60° S.W. The scheelite ore-body (Fig. 4) extends for about 500 feet along the strike of the vein and is known to extend for 580 feet down the dip, but the lower limit of the ore has not been reached by the present workings. A new low-level cross-cut, the 800 cross-cut, was being driven in August 1942, 160 feet below the lowest drift, to give approximately 190 feet more depth on the vein, but the results of this work are not known to the writer.

Form.—The scheelite vein is markedly lenticular, widening from a few inches to several feet in less than 25 feet of drift-length. Although a maximum width of 16 feet has been noted, a range from 3 to 6 feet is more common.

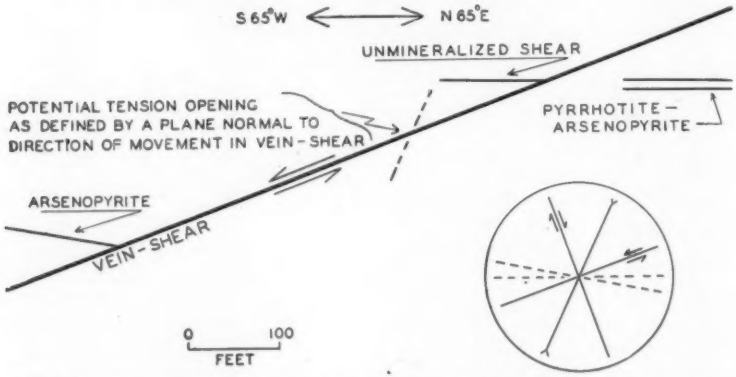


FIG. 5. Fracture pattern and stress diagram of the vein-shear branch shears and direction of tension. Plane of section is perpendicular to common line of intersection of the different breaks and is therefore a true cross-section.

Texture.—The vein is massive and lacks banding or crustification. In places it has a slightly schistose appearance caused by unreplaced wisps of biotite that follow the plane of the vein. Some of the vein-matter consists of a coarse-grained intergrowth of minerals that, because of the development of large crystals, results in a pegmatitic texture. The pegmatitic material is found as small lenses, up to 3 feet long by 2 feet thick on the walls of, and within the vein. The contacts between the pegmatitic material and the wall-rock are gradational and irregular, typical of replacement. The pegmatitic material seeps into the biotized wall-rock and first isolates small slabs of wall-rock and then finally replaces them completely.

Besides pegmatitic material much of the vein consists of fine-grained, sugary quartz, from 0.03 mm to 0.3 mm in grain size, that has replaced much of the earlier, pegmatitic vein-matter and nearly all the other vein-minerals.

Mineralogy.—The ore-minerals include scheelite and ferberite and the accompanying minerals include in order of abundance: quartz, orthoclase,

plagioclase, apatite, biotite, hornblende, chlorite, ankeritic carbonate, chalcopyrite and molybdenite.

Scheelite is the main ore-mineral. It occurs as well-shaped crystals up to ½ inch by 1 inch, in the spaces between the ends of quartz crystals in pegmatitic quartz and as smaller remnants of partly replaced crystals in orthoclase and the fine-grained quartz (Figs. 6, 7, 8). It is therefore later than the pegmatitic quartz and earlier than the fine-grained quartz. In thin-section the scheelite is seen to contain unreplaced patches of ferberite and is therefore

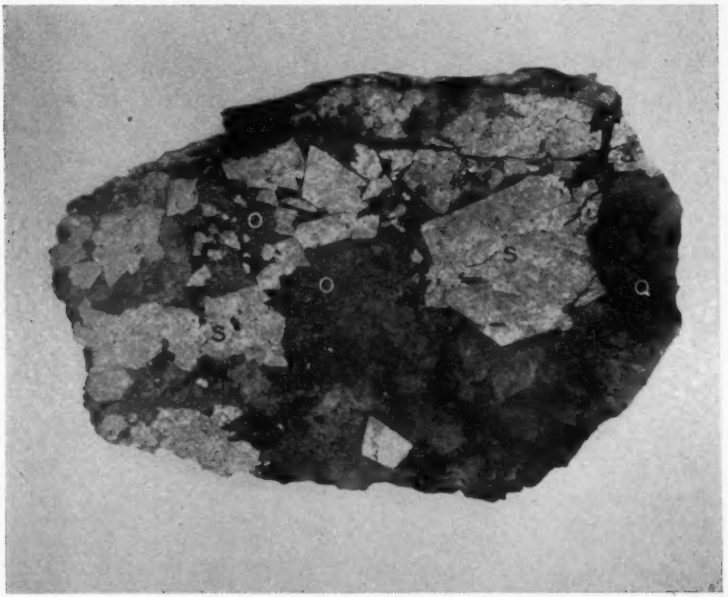


FIG. 6. Polished section of high-grade ore, showing well-defined crystals of scheelite (S), some broken, in a gangue of quartz (Q) and orthoclase (O). The scheelite on the lower right is moulded around the ends of quartz crystals; elsewhere it has been brecciated and replaced by orthoclase. Photographed in ultraviolet light. × 2.4.

younger. Scheelite in many deposits is usually older than any associated ferberite, but in the Red Rose vein it is younger. Tweto [7] has also described scheelite that is younger than ferberite.

Ferberite is not an abundant mineral in the vein and most of that seen was with pegmatitic quartz. Some of it is well-crystallized, in crystals up to ¼ inch by ½ inch, but much of it is moulded around the ends of quartz crystals and wedged between quartz and scheelite. Some occurs as remnant islands

[7] Tweto, O., Scheelite in the Boulder district, Colorado. ECON. GEOL., vol. 42, p. 49, 1947.

SEP 9 1947

in scheelite crystals. The ferberite is therefore younger than the pegmatitic quartz but older than the scheelite. Chemically, the ferberite is very low in manganese, an analysis of typical material yielding only 0.2 percent manganese.

Quartz in the pegmatitic lenses occurs as large, water-clear crystals up to 2 inches in length, surrounded by minerals of later formation. The fine-grained, sugary quartz is massive, without crystal outlines, and in thin-section is seen

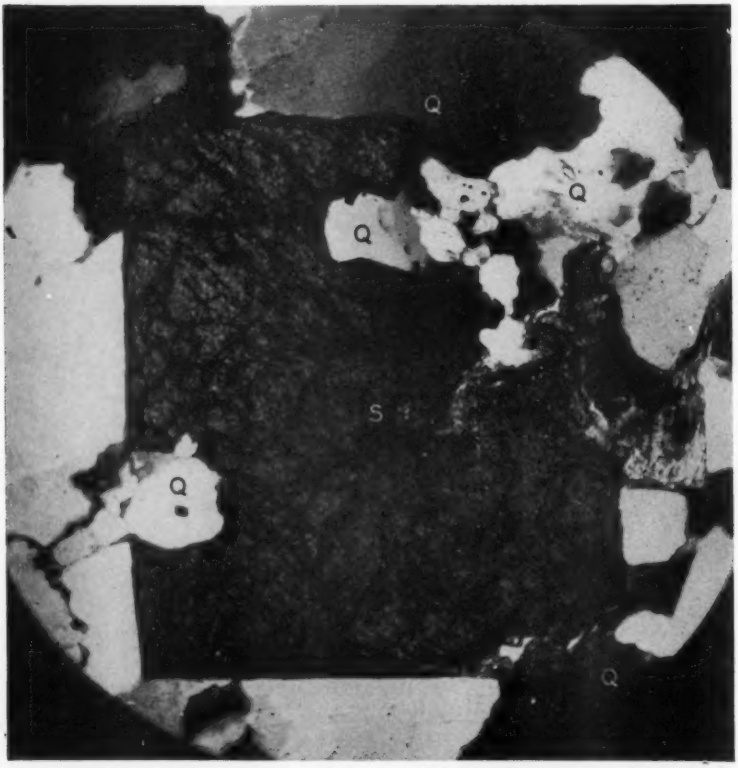


FIG. 7. Thin-section showing crystal of scheelite (S) replaced peripherally by granular quartz (Q). Crossed nicols. × 80.

to consist of anhedral grains filling the interstices between earlier formed minerals. One quarter-inch stringers of quartz cut the two main types of vein-quartz and probably formed during the latest stage of mineralization.

The feldspars include abundant orthoclase and some oligoclase. The orthoclase is very coarse-grained and crystals up to ½ inch by 1 inch are common. It contains fine stringers and blebs of albite and is therefore perthite.

It is later than the crystalline quartz as some of it is moulded around the ends of quartz crystals, but it is earlier than the fine-grained quartz, as it is cut by hairlike stringers of fine-grained quartz (Fig. 9) and occurs as unreplaced islands in the quartz. The orthoclase is also cut by stringers of biotite, and in places large crystals of it are embayed and surrounded by a felted mass of biotite flakes (Fig. 10). Oligoclase occurs with orthoclase, but it is much finer-grained, the crystals being rarely more than $\frac{1}{16}$ inch in size. Indices indicate

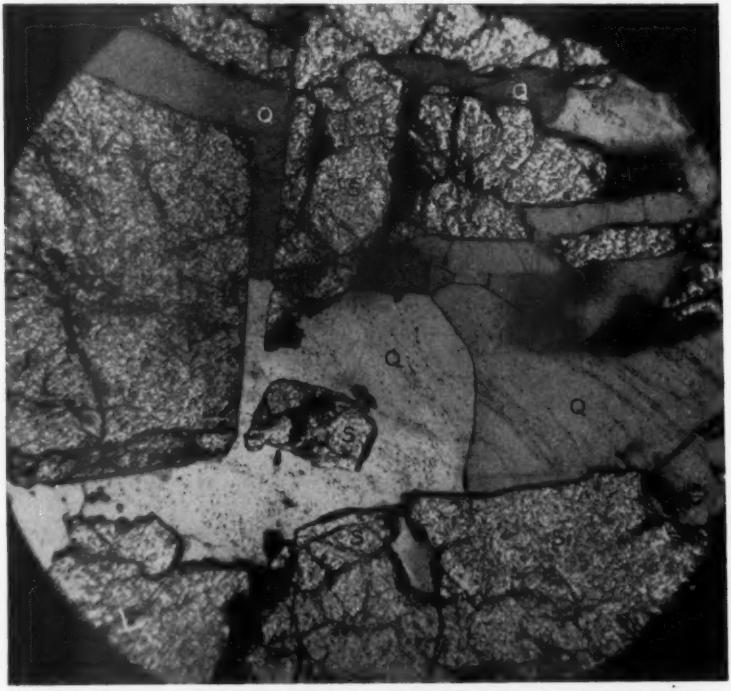


FIG. 8. More advanced stage of replacement in which the quartz (Q) definitely veins and contains islands of unreplaced scheelite (S). Crossed nicols. × 80.

a composition between Ab_{80} and Ab_{85}. The age relations of the plagioclase to the orthoclase are unknown.

Apatite occurs in small clusters of grains commonly associated with scheelite. It is veined by and therefore earlier than the fine-grained quartz (Fig. 11) and also appears to be earlier than the feldspars.

Biotite is found as thick patches of fine, black flakes wrapping around and embaying crystals of earlier formed minerals (Figs. 9 and 12). It is commonly seen as unreplaced wisps in fine-grained quartz. The wisps of biotite

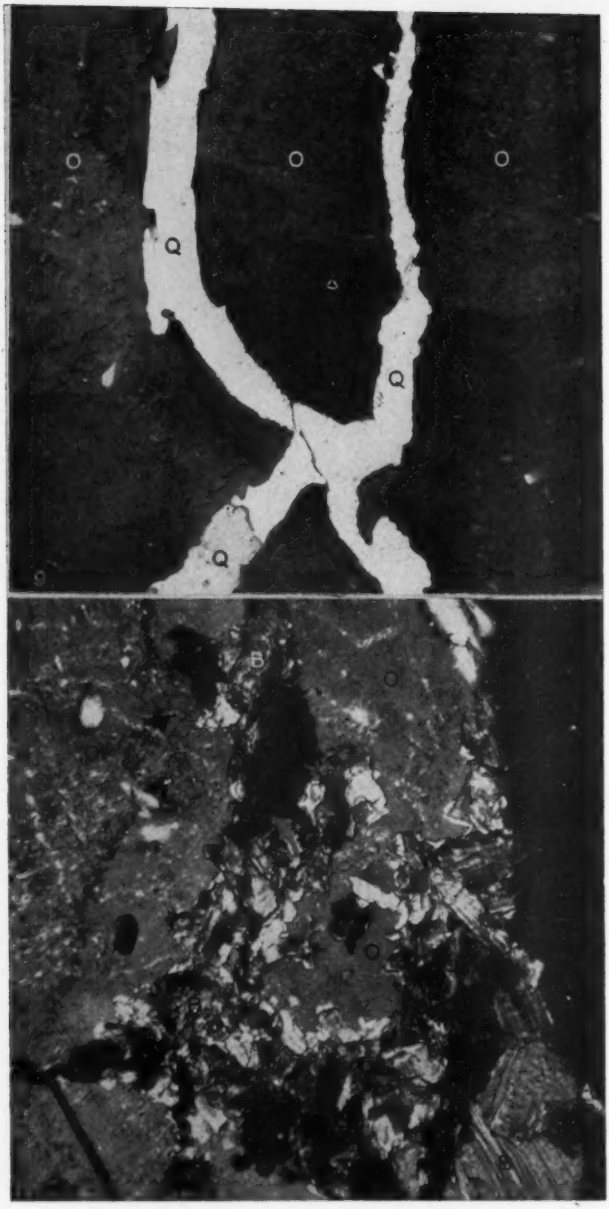


FIG. 9. Quartz (Q) veinlets cutting orthoclase (O) crystals. Orthoclase contains blebs of albite. Crossed nicols. × 85.

FIG. 10. Biotite (B) replacing a large crystal of orthoclase (O). Crossed nicols. × 85.

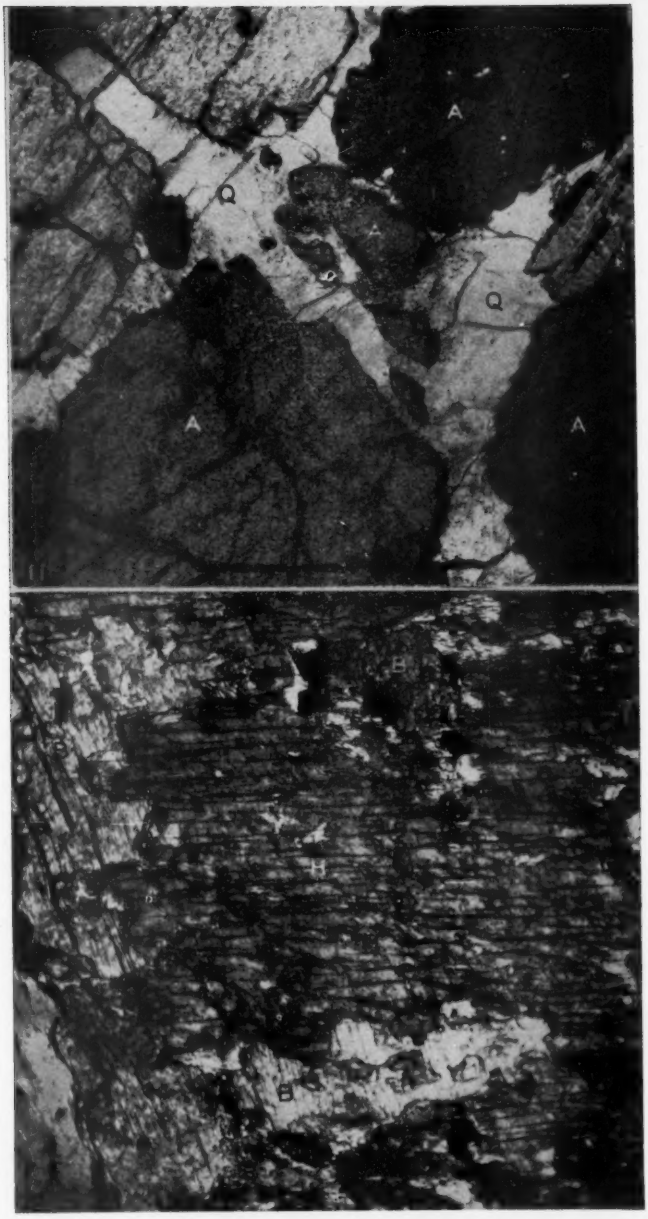


FIG. 11. Quartz (Q) veinlets cutting apatite (A); quartz also contains unreplaced fragments of apatite and partly replaced crystals of biotite (B). Crossed nicols. × 91.

FIG. 12. Biotite (B) replacing a large crystal of hornblende (H) peripherally and along its cleavages. Crossed nicols. × 91.

are parallel to the plane of the vein and where abundant, they impart a schistose texture to the vein-matter. Some of the biotite may be an alteration product from hornblende but where very abundant and in parts of the vein entirely free from hornblende it has probably formed by direct precipitation from vein-solutions.

The vein-hornblende occurs in patches of euhedral crystals, some as large as ½ inch by 1 inch. The indices of the hornblende are $\alpha = 1.644$ and $\gamma = 1.673$, and the extinction angle is 20 degrees; and, although hydrothermal, it is optically and therefore probably chemically similar to the magmatic hornblende found in the diorite and andesite porphyry.

Rosettes and irregular clusters of chlorite, showing anomalous interference colors, were seen in a few sections of the vein-minerals. The chlorite does not replace hornblende and biotite and appears to have been precipitated as chlorite directly from the vein-solutions.

Ankeritic carbonate in small amounts occurs as veinlets cutting many of the vein-minerals.

Sulphides are rare in the ore. Short stringers of chalcopyrite follow the cleavages of some of the hornblende crystals and scattered clusters of grains are found elsewhere in the same crystals. Similar stringers are found in the orthoclase crystals. Larger blebs of chalcopyrite up to 1 inch in diameter have been found in the vuggy quartz. Molybdenite is present but very scarce; it occurs as thin stringers in the quartz.

The paragenesis of the minerals in the scheelite ore-body is; pegmatitic quartz, hornblende, ferberite, scheelite, apatite, perthite, oligoclase, biotite, chlorite, ankeritic carbonate and fine-grained quartz. The position of the small amount of chalcopyrite and molybdenite in the mineral sequence is uncertain.

Sulphides, rare in the ore, are found in veins up to 6 inches thick elsewhere along the vein-shear and in branch veins. These veins consist of cobaltian arsenopyrite, pyrrhotite, and chalcopyrite in a gangue of quartz or rarely of quartz with tourmaline, but never with any scheelite. The cobaltian arsenopyrite contains about 4 percent cobalt. The sulphide veins have not been found cutting the main scheelite vein and are thought to be earlier than the scheelite vein.

Oxidation.—Oxidation of the vein-minerals has not been pronounced. In the vein-outcrop a small amount of the scheelite has altered to a canary-yellow oxidation-product, probably tungstite, which occurs as a dust-film coating quartz crystals, and where protected from surface erosion, occurs as small, 0.5 mm tabular crystals. The total amount of tungstite present is very small, probably because most of it has been carried away by the violent rains, snow and ice characteristic of the mountain slopes at the altitude of the vein-outcrops. Ferberite from the surface is always oxidized to earthy, limonitic masses that commonly possess a cellular or lattice-work texture. It is apparent that the tungsten of the ferberite was carried away by the ground water and the iron left as limonitic material with a lattice-work texture. Underground, oxidation has occurred only where chalcopyrite is found. Limonite replaces chalcopyrite and any nearby iron-bearing vein-minerals such as bio-

tite and ankeritic carbonate. Very little oxidation occurs more than 300 feet below the surface.

WALL-ROCK ALTERATION.

Metasomatic action by vein-solutions on the adjacent wall-rock has been intense in all the rock types except the rather refractory hornfels. Biotization, sericitization and silicification have been the dominant types of wall-rock alteration.

At several places along the vein, biotization of the diorite, the principal wall-rock of the scheelite ore-body, has been complete for widths up to one foot from the vein. The biotized rock consists of a mass of coarse biotite crystals arranged with a flow-like orientation developed under the influence of stresses present near the vein-sheer. Some biotite has migrated from the vein along joints in the diorite for several tens of feet from the vein-shear and is found in sharp-edged veinlets $\frac{1}{16}$ in. to $\frac{1}{4}$ in. thick in the diorite. The amount of biotite in the completely biotized diorite and even in the diorite cut by biotite veinlets is far in excess of the amount that would form by the alteration of the rock-hornblende during thermal metamorphism of the diorite. It is therefore most probable that much of the biotite has been contributed by vein-solutions and its formation is the result of wall-rock alteration by these solutions. In many places, the diorite is cut by veinlets of green hornblende, also contributed by vein-solutions from the main vein-shear, and therefore hydrothermal.

Sericitization by vein-solutions has been strong for about 50 feet from the vein-shear, but beyond this distance, its effects have been very weak. The plagioclase in rocks near the shear has been completely altered to closely-packed sericite that forms bundles pseudomorphic after plagioclase crystals, whereas plagioclase in the same rocks at some distance from the shear is entirely free from sericite.

Silicification of the wall-rock is found at several places along the vein. Where intense it has produced a rock that consists of a mosaic of unstrained, anhedral quartz grains, which, with biotite, produces a typical hornfels texture. This silicified rock differs from the hornfelsed tuff, which is not visibly affected by silicification, only in having a larger grain size. Where silicification has been slight, it has added only a few widely scattered, anhedral grains of quartz to the rocks.

Small blebs and short gashes of hydrothermal apatite are found in the diorite near the vein. This apatite is in addition to the magmatic apatite common as small grains throughout the diorite.

The hornfelsed tuff is the only rock in which marked textural and mineralogical changes have not been brought about by the vein-solutions. However, chemical analyses (Table 4) show a marked increase in the soda content of hornfelsed tuff as the vein is approached. Analyses of argillaceous tuff 500 feet from the vein-shear showed a soda content of 2.35 percent, hornfelsed tuff 150 feet from the vein showed a soda content of 4.3 percent whereas analyses of material adjacent to the vein showed a soda content of 7.34 percent. As blebs or veinlets of albite are not apparent in either hand specimens or thin-

TABLE 4.

PARTIAL ANALYSES OF TUFF TO SHOW ALBITIZATION BY VEIN-SOLUTIONS.
G. C. B. Cave, Analyst.

	1	2	3	4
SiO_2	61.0	58.9	60.0	67.6
CaO	1.3	2.9	2.3	3.4
K_2O	3.81	4.30	2.99	2.1
Na_2O	2.35	4.30	7.34	3.68

1. Argillaceous tuff, 500 feet from vein-shear.
2. Hornfelsed tuff, 150 feet from vein-shear.
3. Hornfelsed tuff, adjacent to vein-shear.
4. Hornfelsed tuff at immediate contact with granodiorite.

sections of the high-soda rock, the increase in soda-content as the vein is reached must be attributed to an increase in the content of albite molecule of the oligoclase of the hornfelsed tuff. Analyses of hornfelsed tuff at the contact of the granodiorite do not show any increase in soda and it is most probable that the albitization described above is a hydrothermal alteration directly related to vein solutions.

STRUCTURAL ANALYSIS OF VEIN-SHEAR AND BRANCH SHEARS.

Direction of Movement Along the Vein-Shear.—The scheelite ore-body occupies a shear that strikes N. 30° W. and dips 60° S.W. The shear is a normal fault in which the hanging-wall has moved down 50 feet and about 150 feet southeasterly with respect to the footwall. The amount and direction of movement were determined by offsets of rock-contacts and by the direction of fluting or grooves in the vein-quartz. Well-defined grooves are very noticeable in an outcrop of vein-quartz above the 200 level, where the grooves are seen to pitch to the south at an angle of 35 degrees from the horizontal.

Branch Shears.—Several breaks, some mineralized and some unmineralized, branch from the vein-shear, some into the hanging and some into the footwall. On the 600 level, two breaks in the footwall strike southerly, and dip 68° W. toward the footwall. These contain quartz, pyrrhotite and cobaltian arsenopyrite. A shear in the hanging-wall outcrops 500 feet east of the ore-body, strikes N. 10° E. and dips 45° N.W. towards the hanging-wall. On the 300 and 600 levels a strong and unmineralized shear in the hanging-wall strikes N. 6° W. and dips 55° S.W. towards the hanging-wall. These breaks are shown in Fig. 5 in a cross-section perpendicular to their common line of intersection.

Fracture-pattern.—The elements of the fracture-pattern include the vein-shear, the branch shears from it, and the plane of potential tension openings within the vein-shear as given by a plane perpendicular to the relative direction of movement of the vein-walls.

The line of intersection of the vein-shear, branch-shears and plane of potential tension openings within the vein plunges about 45° N.W. For the sake of simplicity, the precise direction of plunge, N. 65° W. at 45°, of the

vein-shear and potential tension openings is used in the following discussion. A plane perpendicular to this line strikes N. 65° E. and dips 45° S.E. Because of the several orientations of these different planes, they can only be represented in true cross-section on a plane perpendicular to their common line of intersection. This has been done in Fig. 5.

Stress-diagram.—A stress-diagram similar to that constructed by McKinstry,[8] but based on the fracture-pattern of Fig. 5 has been drawn in the lower right-hand corner of Fig. 5. In this type of diagram the traces of the four planes of maximum stress "on the plane of the paper are as a figure resembling a cross superimposed on an X, the plane of maximum normal stress being indicated by the tail of an arrow without implication as to whether it represents maximum tension or compression."[9] It is impossible to assign directions to the external force because any one of the four possible types of external force, compression, tension, and two directions of shear-couples, will produce identical orientation of the resultant planes of maximum stress (McKinstry, Fig. 2).[10]

The diagram indicates that during the structural history of the vein the shears that formed followed only one major direction of shearing, the direction followed by the vein-shear and its branch-shears. The directions followed by the pyrrhotite-arsenopyrite and the arsenopyrite veins do not correspond exactly to the direction of the vein-shear but the deviations may be because they are wholly in hornfelsed tuff beyond the uniform diorite. It is possible that in passing from diorite to hornfelsed tuff the stress conditions changed sufficiently to account for the deviation from the theoretical direction as defined by the main vein-shear. No reason is evident for the deviation of the unmineralized shear.

Although no tension-breaks paralleling the direction of maximum compression have been formed, they are implied, or potential, in a plane perpendicular to the relative direction of movement of the vein-walls, and their direction is shown as a dashed line in the fracture-pattern of Fig. 4.

LOCALIZATION OF ORE.

Localization of the Ore-Body by Diorite Sill.—Although the vein-shear cuts several rock types, the scheelite ore-body is found only where the shear cuts the upper diorite sill (Fig. 4). The quartz vein is continuous where the shear is in diorite, but loses its continuity where the shear leaves the diorite for hornfelsed tuff or andesite porphyry, and quartz occurs in the vein-shear only as a few, thick, disconnected lenses entirely lacking in scheelite. Sulphide veins, not found with the scheelite ore-body, are common in the vein-shear where it is not in diorite, but they lack scheelite.

The vein-shear is decidedly weaker outside the diorite. In the hornfelsed tuff the break is less clean-cut and consists of only a few narrow shears that die out and come in along the general plane of the break. Although the vein-

[8] McKinstry, H. E., Structural control of ore deposition in fissure veins. Trans. A. I. M. E. Tech. Pub. 1267, 23 pp., 1941.

[9] Op. cit., pp. 3–4.

[10] Op. cit., p. 3.

shear does not perceptibly change in dip and strike in going from one rock to another, the deviation in attitude though small, may have been sufficient to permit the formation of openings along the vein-shear during pre-vein movements, openings sufficient to receive the large amount of vein-matter that accompanied and was part of the scheelite mineralization.

Localization of High-Grade Ore-Shoots.—Two high-grade ore-shoots separated by a lean section are found in the vein. The lean section is 50 to 80 feet long and extends from near the surface to the lowest drift as of the summer of 1942. In general, the pitch of the ore-shoots is to the northwest although for a short distance above and below the 500-foot level it is vertical.

This northwesterly pitch of the high-grade shoots is also the pitch of the potential tension openings within the vein as seen in the fracture pattern and stress diagram of Fig. 5. Although no actual tension breaks have formed, zones of tension pitching northwesterly in the plane of the vein-shear may have developed sufficiently to permit localization of high-grade ore within them.

ORIGIN.

Source of Vein-Solutions.—A large area of granodiorite lies only a few hundred feet east of the scheelite ore-body (Fig. 3) and another large area lies several hundred feet northwest of the ore-body. The contact of the easterly mass dips westward under the scheelite outcrop towards the northwest area and it is probable that the two masses connect at no great depth beneath the vein-outcrop. The plane of the vein-shear approximately parallels the southwestern slopes of this body of granodiorite and it is therefore unlikely that the vein-solutions came immediately from the granodiorite. However, as the vein is close to the granodiorite, and as the minerals are definitely of a high temperature assemblage of minerals, it is likely that the source was in the same magma chamber from which the granodiorite differentiated. A similarity in optical properties and therefore in chemical composition of the hornblende found in the vein and the hornblende found in the diorite suggests that the diorite may also have come from the same magma-chamber as the vein-solutions and the granodiorite.

Nature of Vein-Solutions.—The nature of the vein-solutions is indicated by the wall-rock alteration, mineralogy of the vein and paragenesis of the vein-minerals. The diorite wall-rock next to the vein has been silicified and biotized and the plagioclase largely sericitized. The sericitization of the diorite plagioclase shows that by the time the solutions reached the diorite in their passage upwards from the source-magma, they were alkaline [11] rather than acid. Development work on the vein was not deep enough to determine whether an argillized zone of alteration, such as described by Lovering,[12] lay beneath the sericitic zone of alteration and therefore to determine whether the solutions changed from acid to alkaline on their way up from the source magma or whether, as suggested by Tweto [13] in connection with scheelite in Colorado,

[11] Lindgren, Waldemar, Mineral Deposits. McGraw-Hill, p. 457, 1933.

[12] Lovering, T. S., Tungsten deposits of Boulder County, Colorado. ECON. GEOL., vol. 36, p. 236, 1941.

[13] Tweto, Ogden, op. cit., p. 53.

the solutions were alkaline when they left the magma, the change from acid to alkaline having taken place before the solutions left the magma.

Lovering [14] notes that a strong base such as calcium is necessary for the precipitation of scheelite from an alkaline solution. The silicification and sericitization of the diorite, a high-calcium rock (8.18 percent calcium oxide, see Table 2, column 1), and the early deposition of scheelite and closely related apatite, suggest that the necessary calcium was obtained by reaction of the vein-solutions with the diorite wall-rock. The later plagioclase in the orebody may represent the precipitation of excess calcium obtained in this manner. The paucity of calcium in the hornfels (1.3 to 2.3 percent calcium oxide, see Table 4, columns 1 to 3) and therefore the absence of a precipitating agent for the scheelite, apatite and plagioclase may be the chemical factor contributing to the total absence of those minerals in vein-quartz where the vein-shear cuts hornfelsed tuff.

SPECTRO-CHEMICAL ANALYSES OF MINERALS AND ROCKS.

The tungsten vein contains several minerals that are found also as rock-forming minerals. An especially good opportunity therefore existed to study the variations of minor elements in two groups of minerals that originated from the same magma but which separated during different stages in the differentiation of the magma, the rock minerals early, during the magmatic stage, and the vein minerals later, during the hydrothermal stage. Spectro-chemical analyses were made of carefully cleaned samples of hornblende, biotite, plagioclase, and orthoclase, one group of minerals from the vein and one group from the nearby granodiorite; analyses were also made of wolframite, scheelite and quartz from the vein. The spectro-chemical analyses of minerals are given in Table 5.

Spectro-chemical analyses were also made of 28 samples of rock (see Tables 6–8) to study the variation of the minor elements in the different types of wall-rocks, and, as no tungsten minerals have been found by megascopic or microscopic study in the wall-rocks, to determine whether or not elemental tungsten had become trapped as a minor element in the crystal lattices of minerals, either hydrothermal or magmatic, in the wall-rocks. However, no tungsten was found in any of the wall-rock samples within the limit of spectro-chemical detection by the method used, so that not more than 0.02 percent tungsten could be present.

The distribution of minor elements as given in Tables 5–8 agrees in general with that to be expected from the early studies of Goldschmidt,[15] who concluded that the distribution of minor elements in rocks and minerals is mainly the result of isomorphous replacement of major elements by minor elements with closely similar ionic radii and the same or larger ionic charges or valence.

The variations of the minor elements in the mafic and felsic minerals and in the different types of igneous rocks were similar in kind to those found by

[14] Lovering, T. S., Tungsten deposits of Boulder County, Colorado. ECON. GEOL., vol. 36, pp. 269–271, 1941.

[15] Goldschmidt, V. M., The principles of distribution of chemical elements in minerals. Chem. Soc. London Jour., Pt. I, pp. 660–662, 1937.

TABLE 5.

ANALYSES OF ROCK- AND VEIN-MINERALS.

Sequence of elements according to Soddy's helical arrangement of the periodic system.
Figures refer to spectral line densities.

	Sr	Ba	Sc	Yt	La	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	W	Cu	Ag	Mn	Ni	Co
Granodiorite hornblende	1	1+	5	2	1	3	3	5+	1	3	2+	4	3	2	—	4+	18	5	1	2
Vein hornblende	1.5	4	3	2.5	—	2	2.5	2	1	.5	?	5	2	1	—	4+	6	4	5+	5.5
Granodiorite biotite	1	1+	1	—	—	—	tr	1	tr	2	4+	2	4	1+	—	3+	2	5	2	2
Vein biotite	.5	1+	.5	1	1.5	1	2.5	1.5	tr	.5	4+	3+	1.5	1+	—	5+	1.5	4	4+	3
Granodiorite plagioclase	1	1+	—	—	—	—	tr	tr	28	5+	2	tr	—	1	—	5+	5+	—	tr	5+
Vein plagioclase	1+	1+	—	—	—	—	tr	—	—	tr	3	tr	—	tr	—	5+	1	1	tr	1
Granodiorite orthoclase	1	2	—	—	—,	—	tr	1	3	5+	1	1	—	1	—	4+	5+	1	tr	5+
Vein orthoclase	4+	4	—	—	—	—	tr	—	—	1	?	—	—	—	—	tr	—	tr	—	1
Ferberite	—	1.5	—	13.5	—	9	tr	1	2	*	—	—	—	*	5	2+	1.5	3	—	tr
Scheelite	4	—	—	—	—	—	—	—	1	*	—	—	—	*	3	1+	—	—	—	tr
Quartz	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—

Symbols:

— Metal not detected.

* Tungsten line interferes.

Note:

Not completely confirmed but probably present: P, Ge, Mo, Nd, Ce.

Sb and Bi found only in granodiorite plagioclase.

No As detected; traces of B in some samples.

TABLE 6.

ANALYSES OF HORNFELSED TUFF, ACCORDING TO DISTANCE FROM GRANODIORITE.

	Sr	Ba	B	Sc	Yt	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	Cu	Ag	Mn	Co	Ni
25 ft. from granodiorite (700 ft. from vein)	4+	4+	2	3.5	1	1	3	3	tr	1	?	5	—	3.5	4.5	2	4.5	1.5	4
1030 ft. from granodiorite (150 ft. from vein)	4	4+	3+	2.5	1	1	2.5	2.5	tr	.5	4	4.5	.5	3.5	3.5	2	2	2.5	3.5
1120 ft. from granodiorite (Footwall of vein)	4	4+	1	2.5	tr	tr	1.5	2	tr	1	3	3.5	—	4	4	1	1.5	tr	1
1250 ft. from granodiorite (Hanging-wall of vein)	5	5	2	3.5	.5	tr?	1.5	1.5	2.5	.5	3.5	4	1	3.5	5	3	1	1	2.5
1400 ft. from granodiorite (180 ft. from vein)	4	4+	.5	3	1	tr	2	3	—	1	3	3.5	2.5	3	3.5	1	3	1	2
1700 ft. from granodiorite (550 ft. from vein)	4+	4+	5+	3	tr	tr	2	2.5	tr	1	?	3.5	.5	3	1	1	2.5	1	2
Average	4.1+	4.1+	2.2	3.0	.6	.3	2.1	2.4	.4	1	2.2	4	.6	3.4	3.6	1.3	2.4	1.1	2.5

Symbols as in Table 5.

Note:

La, As, Sb, Bi, W not detected in any of the samples.

TABLE 7.

ANALYSES OF DIORITE, UPPER AND LOWER SILLS.

	Sr	Ba	B	Sc	Yt	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	Cu	Ag	Mn	Co	Ni
1	3.5	2	—	—	4	3.5	tr	—	—	3	—	2	—	tr	5+	1.5	4.5	3.5	4+
2	4+	4+	tr	1	1	tr	3	3.5	tr	1	5	2	—	tr	5+	3	2	4	3
3	2	2.5	tr	1	1	1	3	3	1	tr	4	4.5	.5	2.5	4	—	3	5	2.5
4	4+	4+	tr	3	1	1	4.5	4	tr	.5	3	5	1.5	2	4	1.5	5	2.5	2
5	4.5	4.5	tr	3	1?	tr	3	3	tr	1	3.5	4	1	3	4	3.5	4	tr	1
6	4+	4+	tr	3	1.5	2	3	4	.5	1	4	5	—	3.5	4	2.5	5	3	2
7	4.1	4.1	tr	3	1.2	1.5	3.5	3.6	.2	.8	3.5	4.6	.8	2.8	4	2.5	3.6	1.8	1.6
8	4+	4+	1	1.5	tr	tr	2.5	2.5	tr	1	3+	5	4.5	1	3	2	5	2.5	1
9	4+	4+	tr	1.5	1	1	3.5	3	tr	1	4+	5	—	3	4	2	3.5	1.5	2
10	4+	4+	tr	3	1	1	3	3	tr	1	3	5	1	4	3	4	4.5	2	2
11	4+	4+	.3	2	.6	.6	3	2.8	tr	1	3.3+	5	1.8	2.6	3.3	2.6	4.3	2	1.6
12	4+	4+	.2	2.5	.9	1	3.2	3.2	.1	.9	3.4+	4.8	1.3	2.7	3.6	2.5	3.9	1.9	1.6

Symbols as in Table 5.
Sb, Bi, W not detected, for other notes see Table 6.

1. Silicified diorite, foot-wall of vein-shear.
2. Biotized diorite; biotite: hornblende = 100:0; hanging-wall of vein-shear.
3. Biotized diorite; biotite: hornblende = 78:22; hanging-wall of vein-shear.
4. Biotized diorite; biotite: hornblende = 36:64; 250 feet from vein.
5. Biotized diorite; biotite: hornblende = 18:82; 50 feet from vein.
6. Biotized diorite; biotite: hornblende = <10:90; 300 feet from vein.

(1–6: Upper sill)

7. Average of 4, 5, and 6.
8. Diorite 10 feet from vein.
9. Diorite 100 feet from vein.
10. Diorite 200 feet from vein.

(8–10: Lower sill)

11. Average of 8, 9, and 10.
12. Average of 7 and 11, *i.e.* average of the two diorite sills.

La found only in 1.

TABLE 8.

AVERAGES OF ANALYSES OF THE SEVERAL ROCK TYPES.

	Sr	Ba	B	Sc	Yt	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	W	Cu	Ag	Mn	Co	Ni
Hornfelsed tuff.....	4.1	4.1	2.2	3	0.6	0.3	2.1	2.4	0.4	1	2.2	4	0.6	3.4	—	3.6	1.3	2.4	1.1	2.5
Andesite porphyry.....	4+	4	0.5	1.3	0.6	0.2	2.2	2.8	tr	0.6	4	3.2	—	1.8	—	4.3	1.2	2.8	.5	0.6
Diorite.....	4+	4+	0.2	2.5	0.9	1	3.2	3.2	0.1	0.9	4+	4.8	1.3	2.7	—	3.6	2.5	3.9	1.9	1.6
Granodiorite.....	3.5	4+	tr	1.5	0.5	—	1.5	2	tr	2	3.5	2	1	2	—	3+	1	3.5	1	1
Feldspar porphyry.....	4+	3.7		2.0	1.2	1.3	3.1	5.2	tr	1	4	3.2	1	1.2	—	2.3	1.3	3.2	tr	1.0

Symbols as in Table 5, note as in Table 6.

Bray [16, 17] in his studies of igneous rocks in Colorado, and to those found by Shimer [18] in his study of New England granites and pegmatites.

The spectro-chemical analyses were made by the Chief Analyst of the Department of Mines on an A.R.L. Dietert spectrograph using an aluminized grating with a dispersion in the first order of seven Ångströms per mm; only the ultra-violet spectra were obtained. "Super-pure" grade graphite electrodes, one-quarter inch diameter, were used, operating on a 10 ampere-220 volt direct-current source. Each analysis was run in duplicate and a satisfactory check obtained. The results are given in Tables 5–8 and the figure for each element is the average of the two checks.

The figures for the spectro-chemical analyses are semi-quantitative. The relative concentrations of any one element are expressed numerically by figures which are approximately proportional to the spectral line densities, which in turn are functions of the metal present. A plus sign (+) after a figure in the tables indicates a spectral line density that may be any value above that figure. The figures may be used in comparing the concentration of a single element but may not be used in comparing the concentrations of the different elements with each other.

Minerals.

Elements Detected.—The minor element content of the minerals is given in Table 5. The following elements, both minor and essential, were detected in one or more samples: Na, K, Mg, Ca, Sr, Ba, Al, Sc, Yt, La, Yb, Si, Ti, Zr, Sn, Pb, Ga, V, Zn, Cr, W, Cu, Ag, Mn, Ni, Co, Fe. Table 5 does not include Na, K, Mg, Ca, Al, Si, and Fe, because these elements are major constituents of the hornblendes, biotites and feldspars, and are not found in the tungsten minerals, and therefore were of no value in comparative studies. The other elements detected were used in comparison studies.

Comparison of Mineral Species.—In comparing the variation in total number of minor elements it may be seen from Table 5 that the hornblendes and biotites contain some of all the 19 minor elements listed in the table, whereas the feldspars and the tungsten minerals contain only 12 or less of these 19 minor elements. In explanation of a variation in number of minor elements, Bray [19] has shown that biotite and hornblende permit substitution for a greater number of major elements than the feldspars, and may therefore contain a greater number of minor elements.

There does not seem to be any correlation between the amount or variety of minor elements in the minerals of Table 5 and the packing index [20] of the minerals. All the minerals in this table have a relatively high packing index,[21] and, compared to minerals with a much lower packing index, would tend to

[16] Bray, J. M., Spectroscopic distribution of minor elements in igneous rocks from Jamestown, Colorado. Geol. Soc. America, Bull., vol. 53, pp. 765–814, 1942.

[17] Bray, J. M., Distribution of minor chemical elements in Tertiary dike rocks of the Front Range, Colorado. Am. Mineralogist, vol. 27, pp. 425–440, 1942.

[18] Shimer, J. A., Spectrographic analysis of New England granites and pegmatites. Geol. Soc. America, Bull., vol. 54, pp. 1049–1066, 1943.

[19] Bray, J. M., Geol. Soc. America, Bull., vol. 153, p. 782.

[20] Fairbairn, H. W., Packing in ionic minerals. Geol. Soc. America, Bull., vol. 54, pp. 1305–1374, 1943.

[21] Fairbairn, H. W., idem., pp. 1317–1319.

be relatively free from minor elements, but compared to each other, the variation in index may not be sufficient to account for the variation in minor element content.

In comparing the kinds of minor elements found in the different minerals it may be seen from Table 5 that the hornblendes and biotites are high in the minor elements of relatively small ionic radii, such as V^{3+} (0.75Å);[22] Ni^{2+} (0.78Å); Co^{2+} (0.82Å); Zn^{2+} (0.83Å); Sc^{3+} (0.83Å); Zr^{4+} (0.87Å); Mn^{2+} (0.91Å). These elements, because of the same or larger ionic charge and similar ionic radii, can proxy for the major elements Fe^{3+} (0.67Å); Mg^{2+} (0.78Å) and Fe^{2+} (0.83Å). The feldspars and scheelite are lacking or low in minor elements of small ionic radii because the major elements of these minerals, Na^{1+} (0.98Å); Ca^{2+} (1.06) and K^{1+} (1.33Å) have relatively large ionic radii and are therefore replaceable only by the minor elements of large ionic radii, such as Sr^{2+} (1.27Å) and Ba^{2+} (1.43Å). Ferberite is relatively low in minor elements although its two major constituents Fe^{2+} (0.83A) and W^{6+} (0.65Å) possess small ionic radii, but this may be due to the relatively high ionic charge, 6^+, of tungsten, and the consequent resistance to replacement offered by tungsten to minor elements of lower ionic charge.[23]

Comparison of Vein-minerals with Rock-minerals.—The vein-minerals have as great a variety of minor elements as the rock-minerals, but they have a lesser amount of each of ten elements, Sc, Zr, Sr, Pb, Ga, Zn, Cr, Ag, Mn, and Ni, and a larger amount of only six elements, Sr, Yt, La, Ti, V, and Ni. This indicates a greater purity for the vein-minerals in respect of amount of minor elements. In explanation of this Bray [24] reports Buerger as suggesting that in minerals which are genetically related to the same parent source, the minerals formed at higher temperatures, such as rock minerals, are more tolerant to minor elements than the minerals formed at lower temperatures, such as the vein-minerals.

Comparison of Early Vein-minerals with Late Vein-minerals.—If the vein-minerals are compared on the basis of their paragenesis, which is, from oldest to youngest, hornblende and biotite, plagioclase, orthoclase, ferberite, and scheelite, it is seen from Table 5 that, with the exception of wolframite, not only the number of minor elements, but also the amounts of minor elements, are less in the minerals of later formation. The number of minor elements in the minerals, in order of age from oldest to youngest, is: hornblende and biotite 19, plagioclase 12, orthoclase 7, ferberite 10, and scheelite 4. The more ordered and intolerant structures of later minerals formed at lower temperatures may, as suggested by Buerger, explain the relative "purity" of the later minerals.

Rocks.

The minor element content of the rocks is shown in Tables 6–8. The variation in minor element content of all the rocks has been studied in relation

[22] V^{3+} (0.75 Å): ionic charge and ionic radius respectively for vanadium, data from Wyckoff, R. W., The structure of crystals. Reinhold; pp. 192–193, 1931; and Stillwell, C. W., Crystal chemistry. McGraw-Hill; pp. 417–419, 1938.

[23] Goldschmidt, V. M., op. cit., p. 661.

[24] Bray, J. M., Geol. Soc. America, Bull., vol. 53, p. 783.

LIBRARY SEP 9 1947 MANHATTAN

to the distance from the vein-shear and for the hornfelsed tuff, also in relation to distance from the granodiorite, the heat from the intrusion of which appears to be responsible for the thermal metamorphism of the hornfelsed tuff.

No tungsten was found in any of the rocks either distant from or close to the vein-shear. Although of relatively small ionic radius, tungsten apparently possesses too high an ionic charge (6^+) to enter into the crystal lattices of any of the magmatic or hydrothermal minerals.

Hornfelsed Tuff.—The hornfelsed tuff shows no mineralogical changes as the vein is reached, and correspondingly shows no change in minor element content in that direction. However, towards the granodiorite it shows a slight increase in biotite and shows a corresponding increase in the following minor elements (Table 6): Ga^{2+} (0.62Å); Ti^{4+} (0.64Å); Cu^{1+} (0.96Å); V^{3+} (0.75Å); Ni^{2+} (0.78Å); Mn^{2+} (0.91Å) and Ag^{1+} (0.97Å). Excepting Ag, these are elements with relatively small ionic radii which were seen in Table 5 to occur commonly as minor elements in the biotite, and their increase toward the granodiorite would correspond to an increase in biotite content in that direction. The hornfelsed tuff contains more boron than the other rocks. This is due to occasional veinlets and scattered blebs of tourmaline crystals found only in the hornfelsed tuff.

Diorite.—The silicified diorite contains less V, Ga, Ti, Cr, Zn, Zr, Sr, and Ba than the biotized diorite. This may be explained by the absence in the silicified diorite of biotite, hornblende and feldspars, minerals which were found (Table 5) to contain these minor elements. In comparing the biotized diorite with the unaltered diorite it is found to contain larger amounts of Sn, Pb, Ga, Cu, and Ni and lesser amounts of Sr, Ba, Ti, Zr, V, Zn, Cr, Ag, and Mn than the unaltered rock. This change implies that the biotization of the diorite involves not only the recrystallization of the hornblende but also the addition and subtraction of material represented by additions and substractions of minor elements to the rock as a whole and it is most probable that this material was supplied by hydrothermal solutions from the vein-shear.

A striking similarity in the minor element content of the three specimens of diorite farthest from the shear (Nos. 4, 5, and 6 in Table 7) suggests that the diorite at these distances has been unaffected by hydrothermal solutions and the minor element content of these specimens is that of relatively unaltered diorite.

The minor element content of the diorite of the lower sill (Nos. 8, 9, and 10 in Table 7) is very similar to that of the upper sill. This similarity suggests that the two sills differentiated from the same magma and at about the same stage of crystallization of the magma.

Andesite Porphyry and Feldspar Porphyry.—Both the andesite porphyry and the feldspar porphyry fail to show any gradational change in minor element content as either the vein or the granodiorite were reached.

Comparison of Rock Types.—A comparison of the minor element content of the hornfelsed tuff, diorite, andesite porphyry, feldspar porphyry and granodiorite is shown in Table 8. Many of the variations may be explained by differences mainly in the hornblende, biotite, plagioclase, and orthoclase content

of the rocks and the consequent differences in the kind and amount of proxying elements.

The greater amount of lead in the granodiorite may be explained by the similarity of ionic radii of lead (1.32Å) and of potassium (1.33Å), a major constituent of orthoclase, which is found only in the granodiorite and not in the other rock types. Sandell and Goldich [25] have found that the lead content of igneous rocks is higher in the more silicic varieties.

The greater abundance of copper in the andesite porphyry and diorite as compared with the feldspar porphyry and granodiorite is probably due to a small amount of chalcopyrite in the more basic rocks. Sandell and Goldich [26] suggest that the greater abundance of copper in the more basic varieties of igneous rocks may be due to a similarity in ionic radii of copper (0.75Å) and ferrous iron (0.83Å) and consequent proxying by copper in the more abundant mafic minerals of the basic rocks. However, this is not borne out by Table 5, where copper is as abundant in the felsic as in the mafic minerals.

SUMMARY AND CONCLUSIONS.

The scheelite vein is found in a diorite sill close to a large body of granodiorite.

The ore-body is found only where the vein-shear cuts the thick diorite sill and, although the shear continues into adjacent hornfelsed tuff, no scheelite, and only a little quartz, is found beyond the sill. The pitch of the two high grade ore-shoots in the vein corresponds to the pitch of potential openings within the vein-shear.

The lenticular form and coarse-grained to pegmatitic texture of the vein, the assemblage of high-temperature vein-minerals, and the iron-magnesia metasomatism of the wall-rock, suggest that the vein is a typical hypothermal vein as defined by Lindgren.

The vein does not occur within the granodiorite and it is therefore improbable that the vein-solutions came from the granodiorite body itself. However, it is close to the granodiorite and it is probable that the vein-solutions came from the same deep-seated magma from which the granodiorite and probably the other igneous rocks differentiated.

Sericitization rather than clay-mineral alteration characterizes the wall-rock and the vein-solutions were therefore alkaline rather than acid; and the scheelite, forming early in the sequence of mineral deposition, was precipitated from alkaline solution, along with apatite, by reaction of the solutions with calcium from the diorite, a rock with 8.18 percent calcium oxide. The absence of scheelite in the hornfelsed tuff may be ascribed to chemical as well as to structural causes, for the hornfelsed tuff is low in calcium and would therefore not have precipitated the scheelite and apatite.

Spectro-chemical analyses provide data for generalizations concerning the distribution of minor elements in different minerals and rocks that are in ac-

[25] Sandell, E. B., and Goldich, S. S., The rare metallic constituents of some American igneous rocks. Jour. Geology, vol. 51, no. 3, p. 183, 1943.

[26] Sandell, E. B., and Goldich, S. S., idem, p. 175.

cord with those of other investigators. In addition, the analyses provide data for further conclusions: tungsten, possibly because of an ionic charge larger than that of the common major elements in minerals of the wall-rocks, was found only in the vein and not in any of the wall-rocks, either close to or distant from the vein; hornfelsed tuff showed a gradational change in minor element content as the granodiorite responsible for its thermal metamorphism was reached; the minor element content of the diorite varied directly with the hydrothermal alteration of the diorite as the vein was reached.

Inasmuch as the most important deposits of tungsten are either epithermal or pyrometasomatic, the Red Rose deposit is unique in that it is one of the few hypothermal deposits of scheelite that has produced important amounts of tungsten.

Acknowledgments.—The writer wishes to thank Louise Stevens Stevenson for helpful discussion of the sections on petrology and for reading the manuscript, and G. C. B. Cave, Chief Analyst and Assayer in the Chemical Laboratories of the Department of Mines, for his cooperation in connection with the chemical analyses. Thanks are also due to Mr. Cave and Miss Tannis Martin, laboratory assistant, for the spectro-chemical analyses.

British Columbia Department of Mines,
Victoria, B. C., Canada,
May 1, 1947.

THE SANGDONG TUNGSTEN DEPOSIT, SOUTHERN KOREA.[1]

M. R. KLEPPER.

CONTENTS.

	PAGE
Abstract	465
Introduction	466
Situation and Access	466
Production	466
Korea	466
Sangdong Deposit	467
Geology	468
Stratigraphy and Structure	468
The Ore Beds	470
Main bed	470
Scheelite-bearing rock	471
Rock devoid of scheelite	471
Ore shoot	471
Other ore beds	473
Hornfels marginal to the ore beds	473
Metamorphism and Scheelite Mineralization	473
Hydrothermal Activity	474
Mining	474
Milling	475
Ore Reserve	476
References Cited	476

ABSTRACT.

The Sangdong, one of the principal tungsten deposits of the world, was first exploited on a large scale in 1940. Since that time approximately 850,000 tons [2] of ore has been mined and 14,000 tons of scheelite concentrate that averaged about 52 percent WO_3 has been recovered. The reserve of ore to a depth of 60 meters below the deepest workings is estimated to be about 3,000,000 tons containing 51,000 tons of WO_3.

The deposit consists of metamorphosed lenticular beds in a sequence of gently dipping argillaceous sedimentary rocks. It is thought that these beds were simultaneously metamorphosed and mineralized with scheelite by fluids from a magma. Bismuth, flourine, and other minor constituents were introduced along with the tungsten. Large quantities of silica also may have been introduced. Narrow wolframite-bearing quartz veins of minor economic significance were deposited during the period of hydrothermal activity that followed the metamorphism and the deposition of scheelite.

[1] Published by permission of the Director, U. S. Geological Survey. The writer examined the Sangdong deposit while attached as a Scientific Consultant to Natural Resources Section, GHQ, Supreme Commander for the Allied Powers. This assignment was part of a cooperative research program of the Geological Survey and the Office, Chief of Engineers, U. S. Army.

[2] The metric system is used throughout this paper.

Six beds, or groups of thin beds, have been metamorphosed. Scheelite is found in all of these beds, but most of the commercial concentrations are in one bed, known as the "Main bed." In this bed much of the scheelite is in one large ore shoot that is as much as 525 meters long, between 4 and 5 meters thick, and has been partly mined for 200 meters down dip from the outcrop. Geologic conditions suggest that more ore may be found at greater depth in the Main bed or in unexplored portions of the other beds.

INTRODUCTION.

Tungsten minerals were mined in the Sangdong area at least as early as 1916. During World War I, and sporadically during the following two decades, wolframite was won from narrow quartz veins at the Ungbong-san Mine (Lat. 37° 37′ 50″ N. and Long. 128° 48′ 40″ E.) and a small quantity of scheelite was produced from beds of "tactite" at the nearby Sun-gyong-san Mine (Lat. 37° 08′ 37″ N. and Long. 128° 50′ 00″ E.). Until 1939, when intensive exploration of the "tactite" in and near the Sun-gyong-san Mine was undertaken, the annual output of tungsten concentrate from this area probably averaged less than 20 tons and never exceeded 100 tons. Exploration in 1939 and 1940 led to the discovery of the large Sangdong scheelite ore body from which 14,000 tons of concentrate have since been produced and in which a reserve equivalent to several times the past production is indicated.

SITUATION AND ACCESS.

The entry to the Main adit of the Sangdong Mine (Lat. 37° 08′ 41″ N. and Long. 128° 50′ 17″ E.) is at the village of Iyonnae near the head of a short, south-flowing tributary of the Oktong-ch'on (river). Iyonnae is in the southeastern part of Sangdong-myon (township) in eastern Yongwol-gun (county), Kangwon-do (province). A gravel road, passable to trucks, leads 90 kilometers west to Chech'on, which is 150 kilometers by railroad east-southeast of Seoul, the capital of southern Korea. A mountain road, 25 kilometers long, once connected the mine to Chor-am, terminus of the Samch'ok Coal Mine Railroad that extends 55 kilometers northward to Mukho, a small port on the east coast of Korea, but this road was washed out by a cloudburst in 1946.

The Sangdong Mine is in a sharply dissected part of the Taebaek Mountain Range. Slopes in the vicinity of the mine average about 35 degrees and rise as much as 500 meters above the bottoms of narrow, sinuous, V-shaped valleys to attain altitudes of more than 1,000 meters above sea level. Taebaek-san, one of the principal peaks of the range with an elevation of 1,561 meters, is eight kilometers southeast of the deposit.

PRODUCTION.

Korea.—Prior to 1933 Korea's total output of tungsten concentrate had been only a few thousand tons, and most of this had been produced during the period 1916–1919. The Ungbong-san Mine and the Sun-gyong-san Mine were major contributors to this early output.

Japan's demand for tungsten increased greatly during the 1930's and in response to this stimulus Korea's output of tungsten concentrate gradually

grew from 150 tons in 1933 to 11,500 tons in 1944. During 1933–1945, Korea's output of tungsten concentrate amounted to 36,000 tons, 60 percent of the total consumed in the Japanese Empire. Mines in southern Korea, the area now occupied by American troops, accounted for about 55 percent of Korea's total output.

Sandong Deposit.—Since 1940 approximately 850,000 tons of ore have been mined from the Sandong deposit. Eighty-five percent of this ore came from the Sangdong Mine and 15 percent from the Sun-gyong-san Mine. Concentrates containing 7,523 tons of WO_3 were recovered from this 850,000 tons of ore. This is equivalent to 69 percent of southern Korea's total output, or 18 percent of the total consumption of WO_3 in the Japanese Empire from 1938 through 1945. The annual production of the Sangdong Mine for the period 1940-45 is shown in Table 1, and the combined output of the Sangdong and Sun-gyong-san Mines is compared with the total output of southern Korea and the total consumption for the Japanese Empire in Table 2.

TABLE 1.

PRODUCTION OF SANGDONG MINE.

Year	Ore Mined (tons)	Grade of Ore (% WO_3)	Concentrate Recovered (tons)	Grade of Concentrate (% WO_3)	WO_3 Content of Concentrate (tons)
1940.....	0	—	0	—	0
1941.....	27,610	1.8	415	59.5	247
1942.....	94,830	2.0	1,508	48.3	727
1943.....	218,070	1.6	3,119	55.8 (?)	1,732 (?)
1944.....	275,776	1.7	4,646	51.6	2,398
1945.....	112,836	1.8	1,786	50.5	903
1946[a].....	[b]	—	500	50	250
Total.....	729,122[c]	1.73	11,974	52.4	6,257

[a] Approximate. [b] No data. [c] Incomplete.

TABLE 2.

PRODUCTION OF SANGDONG AND SUN-GYONG-SAN MINES.
(Tons of WO_3 contained in concentrates.)

	1938	1939	1940	1941	1942	1943	1944	1945	1946	Total
Sangdong Mine.....	0	0	0	247	727	1,732	2,398	903	250	6,257
Sun-gyong-san Mine.	50[a]	150[a]	300[a]	350	367	49	0	0	0	1,266
Total.....	50[a]	150[a]	300[a]	597	1,094	1,781	2,398	903	250	7,523
Percent of southern Korea's output[a]...	42	55	71	53	65	72	69	73	100	69
Percent of Japanese Empire's consumption[a].....	2	4	5	10	18	19	31	71	—	18

[a] Approximate.

During 1944 and the first 8 months of 1945 bismuthinite concentrate was recovered as a by-product of the concentration of scheelite at Sangdong. The

total output was between 500 and 600 tons of concentrate that contained between 40 and 50 percent Bi, sufficient to place the Sangdong Mine among the world's major producers of bismuth during this period.

GEOLOGY.

Stratigraphy and Structure.

The Sangdong area is in the gently dipping south limb of the broad symmetrical syncline of Paleozoic and early Mesozoic rocks that extends for about 30 kilometers westward from the productive part of the Samch'ok Coal Field (1).[3] The syncline consists of rocks ranging in age from Cambrian to Triassic, but within one kilometer of the Sangdong Mine only the Cambrian and Ordovician formations listed in Table 3 crop out (Fig. 1).

TABLE 3.

GEOLOGIC COLUMN AT THE SANGDONG MINE.[b]

Thickness	Formation Name and Description	Series	System	Age
Up to 1,000	*Not subdivided into formations.* Thick- and thin-bedded limestone, vermicular limestone, and marl, with intercalations of shale and quartzite.	Great Limestone	Choson	*Ordovician*
200	*Myobong formation* Mudstone, siltstone, shale, marl; locally phyllite, mica schist, hornfels, and tactite (contains scheelite deposits).	Yangdok		*Cambrian*
More than 200	*Changsan formation* White, light-pink quartzite.			
	Unconformity			
Unknown	*Not subdivided into formations.* Dark-gray mica schist and quartzite.	Taebaek-san	Unnamed	*Pre-Cambrian*

[b] Modified after maps and sections by Shiraki (1).

The rocks at Sangdong strike N. 75° W. and dip between 15° NE. and 30° NE. They lie unconformably upon pre-Cambrian schist. This unconformity passes with an easterly trend about two kilometers south of the mine. All commercial concentrations of scheelite are in lenticular beds of "tactite" within the Myobong formation, which, in the vicinity of the mine, is predominantly quartzose hornfels.

No igneous rocks have been found in or near the mine, but about seven kilometers to the east-southeast the Cambrian and Ordovician rocks are cut by a boss of granite porphyry and by a few narrow porphyry dikes. Shiraki

[3] References are at end of paper.

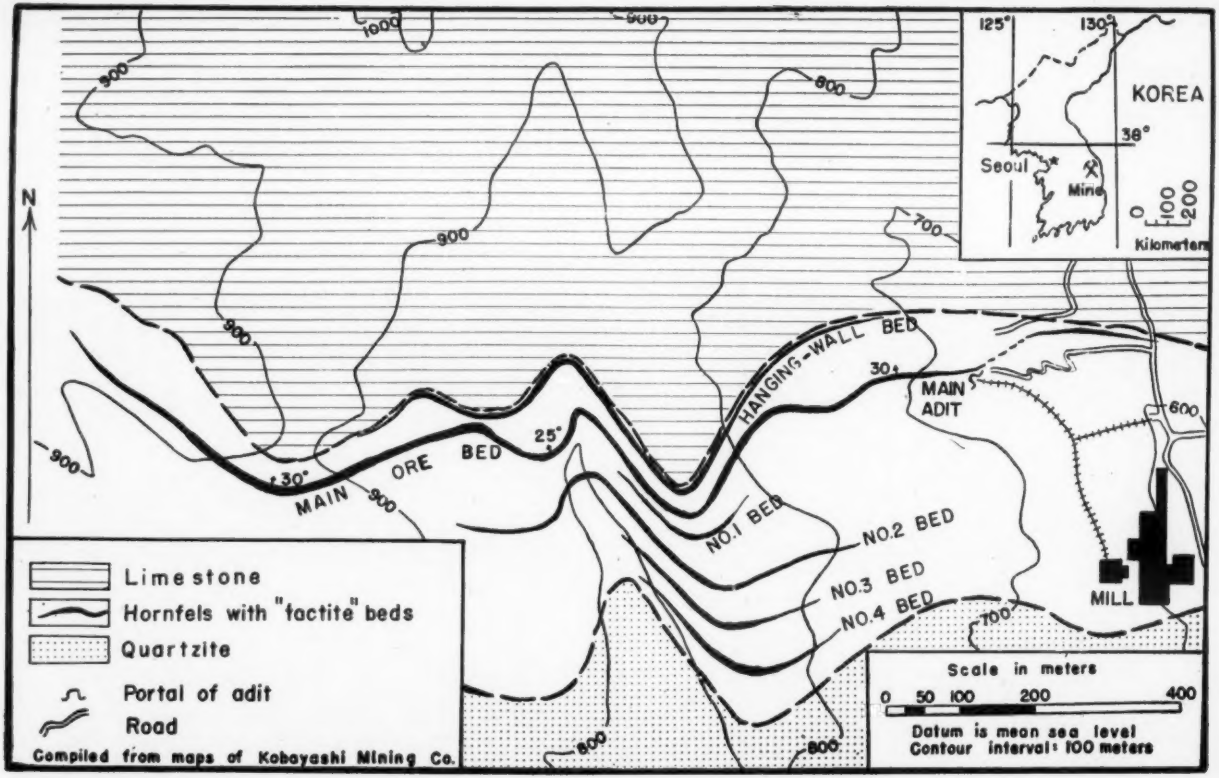


FIG. 1. Geologic map of the Sangdong tungsten area.

(1) concludes that these igneous rocks were intruded during uppermost Cretaceous time.

No major faults have been recognized in the Sangdong area, but many minor faults are exposed in the mine. Most of them are normal faults that strike between due North and N. 15° E. and dip steeply to the west. The displacement along most is only one or two meters, but along a few it is eight or ten meters. One or two reverse faults of north-northeast trend and small displacement have been observed. Part, if not all, of the movement along both the normal and the reverse faults was subsequent to the deposition of scheelite.

The Ore Beds.

At Sangdong, commercial concentrations of scheelite ore are confined to a few lenticular beds within the Myobong formation that have been reconstituted by recrystallization and metasomatism. Six beds are known that have been metamorphosed and mineralized with scheelite; some general information about them is shown below:

Name	Approximate Depth Below Top of Myobong Formation	Strike Length	Average Thickness
Hanging-wall bed	10 meters	700 m.	7 m.
Main bed	40 m.	1,500 m.	4.5 m.
Footwall no. 1 bed	50 m.	150 m.	1.0 m.
Footwall no. 2 bed	100 m.	450 m.	0.5 m.
Footwall no. 3 bed	150 m.	200 m.	0.4 m.
Footwall no. 4 bed	180 m.	200 m.	0.5 m.

Only the Main bed has been exploited on a large scale. In the thick Hanging-wall bed only a few small minable concentrations of scheelite have been found. The footwall beds are narrow and generally low-grade, but some ore has been mined from the near-surface part of two of them.

Main bed.—The Main bed is between four and five meters in thickness almost everywhere, strikes easterly, and dips from 15° north to 30° north in conformity with the other beds of the Myobong formation. The Main bed comprises three distinct types of rock, one scheelite-bearing and the other two devoid or almost devoid of scheelite. Of the two types of rock that contain little or no scheelite, one is hornfelsic and the other is garnetiferous. The scheelite-bearing rock and the barren hornfelsic rock make up most of the Main bed. The garnetiferous rock is distinctly subordinate, having been found in only one small part of the Main bed. Most commonly, the scheelite-bearing rock and the hornfelsic rock are in well-defined layers or lenses that are more or less parallel to the margins of the Main bed. These layers or lenses range in thickness from about one millimeter to at least ten centimeters. Less commonly these two types of rock are not separated into well-defined layers, but form patchy or irregular intergrowths that may transgress bedding. The scheelite-bearing rock appears to predominate in the central part of the Main bed and the hornfelsic rock in the marginal parts.

(*a*) *Scheelite-bearing rock.*—Typically the scheelite-bearing rock is even-textured and medium- or fine-grained. In most specimens the size of the mineral grains is between 0.5 and 1.5 mm. Crystals larger than 4 mm. in maximum dimension are unusual. The mineral composition of the rock is simple. Quartz is the chief component, ranging from 50 percent to 95 percent by volume in the specimens examined. Intergrown with the quartz are subordinate quantities of biotite varying up to 40 percent, scheelite up to 25 percent, fluorite up to 10 percent, apatite up 2 percent, and sulphide minerals up to 5 percent. Typically scheelite makes up between 1 and 5 percent of the rock. Pyrrhotite is the most abundant of the sulphide minerals; molybdenite, bismuthinite, chalcopyrite, and pyrite are much less common.

In thin-section the quartz appears as an aggregate of interlocking anhedra of about the same size. Euhedra and subhedra of scheelite and apatite are enclosed within grains of quartz or are crystallized with them as individuals of the aggregate. Biotite and fluorite are commonly interstitial to the quartz. In a few sections biotite and quartz mutually enclose each other, and in one scheelite is molded around grains of quartz.

(*b*) *Rock devoid of scheelite.*—Within the Main bed two distinct types of rock that contain little or no scheelite have been recognized. One of them is an even-textured hornfelsic rock and the other a porphyroblastic garnet rock. The hornfelsic rock consists of an intergrowth of diopside, hornblende (or actinolite), and quartz with subordinate biotite, sulphide minerals, and locally fluorite. The other rock is characterized by porphyroblasts of garnet in a fine-grained felted aggregate of chlorite(?), diopside, and quartz.

The hornfelsic rock is interlayered with or irregularly intergrown with the quartzose scheelite-bearing rock. The relative proportion of these two types of rock varies from place to place in the Main bed, but their volumes are probably about equal in the bed as a whole.

The rock with porphyroblasts of garnet is volumetrically unimportant. It was observed by the writer for a short interval on two different levels of the Sangdong Mine. The miners state that it continues from the outcrop to the deepest level of the mine as a narrow band in the Main bed normal to the strike.

(*c*) *Ore shoot.*—Most of the total output of ore from the Sangdong Mine has come from one ore shoot in the Main bed. This ore shoot averages 4.5 meters in thickness. It is 225 m. long at the outcrops, attains a maximum strike length of 525 m. at a depth of 100 m. beneath the outcrops, and is about 250 m. long on the Main adit, the deepest fully explored level of the Mine (Fig. 2). All but about 50,000 tons of the 750,000 tons of ore mined at Sangdong came from this one ore shoot. The distribution of scheelite within the ore shoot, as shown on the Kobayashi Company's assay map, is surprisingly uniform. The average grade of the ore mined has been about 1.75 percent WO_3.

Marginal to the ore shoot is an aureole of rock that does not differ appreciably in gross appearance from the rock within the ore shoot, but that contains an average of only 0.25 to 0.5 percent WO_3. The miners state, and samples collected by the writer tend to confirm, that within the ore shoot the Main bed contains proportionately more of the quartz-biotite rock whereas outside of

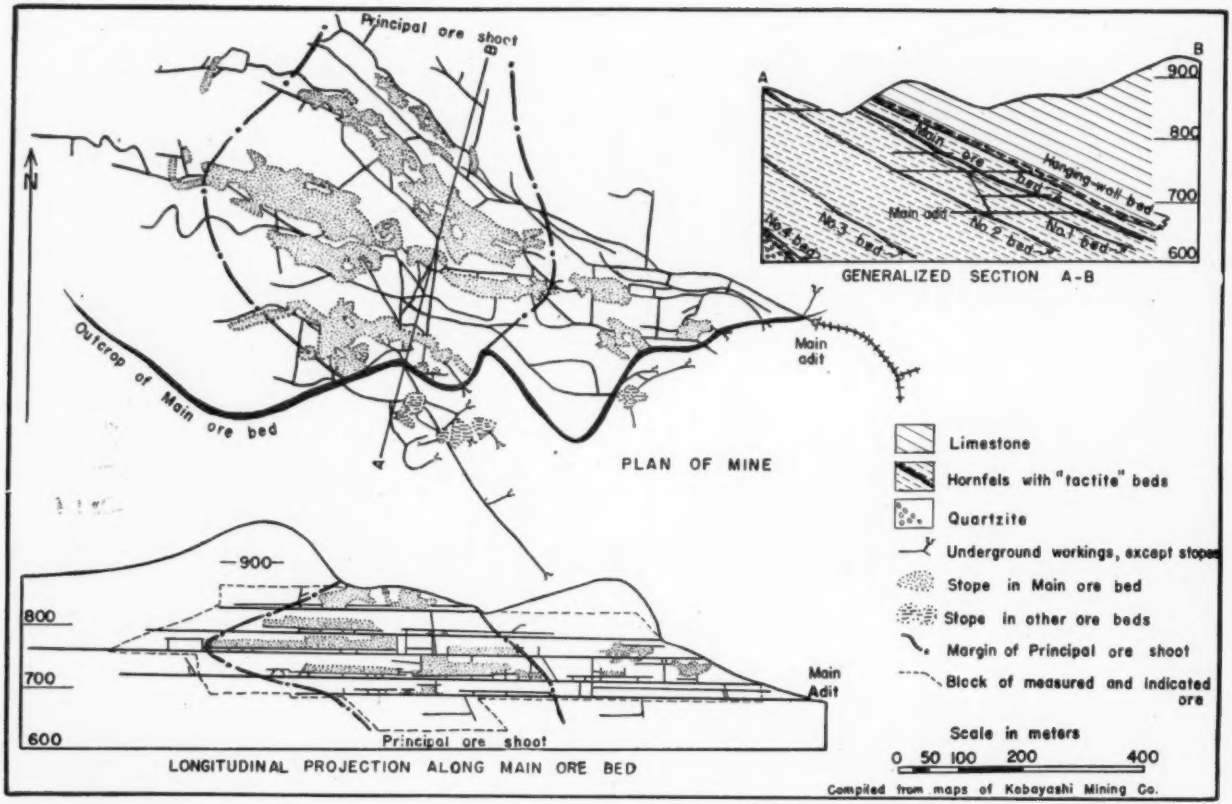


FIG. 2. Sangdong tungsten mine.

the ore shoot diopside-hornblende (or actinolite) rock predominates. In this aureole of low-grade ore are scattered small pockets of high-grade ore.

Other ore beds.—The writer did not examine the other five ore beds at Sangdong. These beds have contributed only a small fraction of the total output of scheelite from the mine, and they are reported to contain only a few small bodies of minable ore. In physical appearance they are said to resemble the Main ore bed, being somewhat coarser grained than the enclosing hornfels and having a rusty weathered surface.

Hornfels marginal to the ore beds.—The hornfels is a dense, fine-grained aggragate of quartz, hornblende (or actinolite), diopside, and biotite. Plagioclase is uncommon. The proportions of these minerals were different in each of the specimens examined under the microscope, but in all but one quartz predominated. Most of the specimens of hornfels closely resemble the hornfelsic diopside-hornblende rock of the Main bed, but are perceptibly finer grained and contain less sulphide minerals.

Metamorphism and Scheelite Mineralization.

At Sangdong the rocks were reconstituted by recrystallization or by metasomatic replacement, or by both, and at the same time scheelite was deposited along a few favorable beds or groups of beds. The criteria by which metasomatic rocks can be distinguished from rocks that have been recrystallized without the addition of extraneous components are not always irrefutable or subject to only one interpretation. This is particularly true at Sangdong where reconstitution of the rocks has been thorough. If the rock that is now the Main bed was originally a calcareous sediment, then metasomatism has been the dominant process in metamorphism, but if the rock was a siliceous sediment, then recrystallization has been the dominant process.

There is little question that W, Bi, Mo, Cu, F, P, and S were introduced by migratory fluids of magmatic origin, and combined with one another or with elements in the beds to form scheelite, molybdenite, bismuthinite, chalcopyrite, fluorite, and apatite, but there is a question whether quartz and biotite, the two principal components of the ore beds, are the product of simple recrystallization, or of metasomatism, or of a combination of these processes.

Microscopic study of the ore indicates to the writer that at Sangdong the metamorphism of the sedimentary rocks and the deposition of scheelite were essentially contemparaneous and were accomplished by the same fluids.

Structural relations indicate that the fluids must have migrated hundreds, and possibly thousands, of meters before depositing their load, for the nearest known igneous rock in this region of high relief is six or seven kilometers from the Sangdong deposit. This observation suggests to the writer that the position of igneous contacts has been of little or no importance in the genesis of the Sangdong deposits, but that favorable sedimentary horizons and channelways, such as fractures and bedding planes along which fluids could migrate outward from a chamber of partly consolidated magma, were of paramount importance. The writer believes that the body of granite porphyry and the scheelite are progressive manifestations of the same period of igneous activity.

FIG. 2. Sangdong tungsten mine.

The writer prefers to call the Sangdong tungsten deposits high-temperature metasomatic, even though they were probably formed by processes very similar to those responsible for many of the so-called contact-metamorphic tungsten deposits (2a, 3a). The term contact-metamorphic, if applied to the deposits at Sangdong, would be a misnomer both descriptively and genetically. Furthermore, Lindgren's term pyrometasomatic deposit is objectionable, for it specifies (18) that the deposits are at or near an igneous contact, and at Sangdong proximity to a contact cannot be demonstrated.

To refer to the ore at Sangdong as tactite may be objected to, for Hess's original definition (4) states ". . . formed by the contact metamorphism of limestone, dolomite, or other soluble rocks. . . ." Furthermore, the ore rock at Sangdong is unlike the typical scheelite-bearing tactites that have been described by Hess and Larsen (2b), Kerr (5), Rastall and Wilcockson (6), Lemmon (7, 8, 9), Smith and Guild (10), Roberts (11), Jahns (12), Hobbs (13, 17), Fries and Schmitter (14), Wiese and Cardenas (15), Johnston and Vasconcellos (16), and others (3b). In deference to these somewhat philosophical objections the writer in this paper refers to the rock of the ore bed as "tactite."

Hydrothermal Activity.

Subsequent to the formation of the "tactite" and the deposition of scheelite, hydrothermal solutions invaded the rocks of the Sangdong area. Two manifestations of these solutions have been recognized: (1) deposition of quartz veins that contain molybdenite, wolframite, and subordinate scheelite and bismuthinite and (2) partial chloritization of biotite and amphibole and partial replacement of quartz and other minerals by calcite.

The quartz veins strike and dip in many directions and are up to 50 centimeters in thickness. They are most prominent at the Ungbong-san Mine, where formerly they were exploited for wolframite, and in the Main bed at the Sangdong Mine, where they contribute a little wolframite, scheelite, molybdenite, and bismuthinite to the mine-run ore. In milling, the molybdenite is not recovered. Wolframite and molybdenite, the two most abundant ore minerals, are irregularly distributed within the veins. Koreans familiar with the mine state that molybdenite predominates over wolframite in the veins in the upper levels of the mine and that wolframite predominates in the lower levels. Commonly the richer parts of the veins consist of a narrow marginal portion of chalcopyrite, pyrrhotite, and pyrite and a thicker central portion of vuggy, milky quartz in which blades of wolframite and plates of molybdenite are oriented normal to the margins of the vein and crystals of the other sulphide minerals are disseminated at random. Many of the wolframite crystals are rimmed or veined by scheelite.

MINING.

Prior to 1939 the surficial portion of the Main ore bed, of the Hanging-wall bed, and of one or two of the footwall beds had been explored at the Sun-gyong-san Mine, but only a small quantity of scheelite concentrate had been produced. From 1940 until August 1945 the Kobayashi Mining Company exploited the

Main bed to a depth of 200 meters below the highest outcrop of the principal ore shoot through four adits at intervals of 50 to 70 meters along the incline (25 to 35 meters vertical) and two winzes below the lowest adit (Main adit) (Fig. 2). Since August 1945 the mine has been operated intermittently on a small scale by Koreans.

FIG. 3. Sangdong mill.

Principal haulage adits were generally driven in the footwall of the ore bed or in sub-commercial portions of the bed. Exploratory and development drifts were advanced in the bed in and near the ore shoot. Blocks of ore to be stoped were outlined by inclined raises and sub-levels in the bed. Ore was mined from open stopes that were advanced upward from the adit levels or sub-levels (Fig. 2). In places the slope of the stopes permitted loading by gravity, but where the slope was low shoveling was necessary. Transportation to the mill, 350 meters from the portal of the Main adit, was by electric locomotive.

MILLING.

The mill at Sangdong, designed to treat 800 tons of ore daily, was completed in 1942 (Fig. 3). By 1946, more than 700,000 tons of ore was treated from which 11,500 tons of concentrate that averaged 52.4% WO_3 was recovered. Recovery averaged only 48% of the WO_3 contained in the ore. The remaining 52% of the WO_3 has been dissipated as tailings down the canyon in which the mill is situated. Prior to 1942, ore from the Sun-gyong-san and Sangdong Mines was treated in a small mill that has since been dismantled.

In the Sangdong Mill the ore was crushed and then ground in ball mills to 90% minus 100 mesh. A sulphide concentrate was first removed by flotation. Scheelite was then separated from the sulphide tailings by a second flotation that gave a concentrate that contained 10 to 20% WO_3. This low-grade tungsten concentrate was then tabled to a grade of 50 or 55% WO_3.

Late in 1943 flotation cells were installed to recover from the sulphide concentrates a bismuthinite concentrate that contained 40 to 50% Bi. Since August 1945 the Korean operators have experimented with the mill intermittently, but have not been able to increase either the percentage of recovery or the grade of the concentrates produced.

It is reported that during World War II more than 1,000 persons were recovering fine-grained scheelite from the stream as far as 10 kilometers below the mill by panning and blanketing. This scheelite had been discharged into the stream in the mill tailings.

ORE RESERVE.

According to engineers of the Kobayashi Mining Company the reserve of positive (measured and indicated) ore in the Sangdong Mine in 1945 was 2,280,000 tons that averaged 1.7% WO_3 and contained 38,800 tons of WO_3. The reserve of possible ore was 1,000,000 tons that averaged 1.3% WO_3 and contained 13,000 tons of WO_3. Most of this reserve is in the principal ore shoot in the Main bed, between the outcrop and a depth of 60 meters below the Main adit level. Less than 100,000 tons of ore have been mined since this estimate was made. Although the order of magnitude of the reserve cited above is believed correct, recalculation of the basic data by American geologists would probably give a lower ratio of measured and indicated ore to inferred ore.

The geology of the deposit suggests that commercial ore probably will continue to a depth considerably greater than that used in the computation of reserves. There is little justification for believing that the principal ore shoot has been nearly bottomed even though it is somewhat shorter at the Main adit level than at a higher level. Even in the deepest workings no igneous rocks have been encountered, nor has the grade of ore diminished.

Detailed mapping and careful prospecting and exploration of the other beds in the vicinity of the mine might lead to the discovery of other shoots of minable ore.

REFERENCES CITED.

1. Shiraki, Takuji, Samch'ok anthracite field, Institute of Fuels and Ore Dressing, Record of Survey of Korean Coal Fields, v. 14, 1940. See geologic map and sections K–L and M–N.
2. Hess, F. L. and Larsen, E. S., Contact metamorphic tungsten deposits of the United States, U. S. Geol. Survey Bull. 725–D, 1921. (a) pp. 248–255; (b) pp. 259–309.
3. Kerr, P. F., Tungsten mineralization in the United States, Geol. Soc. America Memoir 15, 1946. (a) pp. 41–61; (b) pp. 93, 107, 109, 115–118, 138–148, 151–171, 174–176, 182–194, 199–200, 203–206.
4. Hess, F. L., Tacite, the product of contact metamorphism, Am. Jour. Sci., 4th Ser., vol. 48, pp. 377–378. 1919.
5. Kerr, P. F., Geology of the tungsten deposits near Mill City, Nevada, Nevada Bur. Mines Bull., vol. 28, No. 2. 1934.

6. Rastall, R. H. and Wilcockson, W. H., Tungsten ores, Monographs on Mineral Resources, John Murray, London, p. 41. 1920.
7. Lemmon, D. M., Tungsten deposits in the Tungsten Hills, Inyo Co., Cal., U. S. Geol. Survey Bull. 922–Q, pp. 503–505. 1941.
8. Lemmon, D. M., Tungsten deposits of the Benton Range, Mono County, Cal., U. S. Geol. Survey Bull. 922–S, p. 589. 1941.
9. Lemmon, D. M., Tungsten deposits in the Sierra Nevada near Bishop, Cal., U. S. Geol. Survey Bull. 931–E, p. 86. 1941.
10. Smith, W. C. and Guild, P. W., Tungsten deposits of the Nightingale Dist., Pershing Co., Nev., U. S. Geol. Survey Bull. 936–B, pp. 46–47. 1942.
11. Roberts, R. J., The Rose Creek tungsten mine, Pershing Co., Nev., U. S. Geol. Survey Bull. 940–A, p. 7, 1943.
12. Jahns, R. J., Beryllium and tungsten deposits of the Iron Mountain Dist., Sierra and Socorro Counties, New Mexico, U. S. Geol. Survey Bull. 945–C, p. 54. 1944.
13. Hobbs, S. W., Tungsten deposits in Beaver County, Utah, U. S. Geol. Survey Bull. 945–D, pp. 89, 96, 100, 101. 1945.
14. Fries, Carl, Jr. and Schmitter, E., Scheelite deposits in the northern part of the Sierra de Juarez, Northern Territory, Lower California, Mexico, U. S. Geol. Survey Bull. 946–C, p. 81. 1945.
15. Wiese, J. H. and Cardenas, D., Tungsten deposits of the southern part of Sonora, Mexico, U. S. Geol. Survey Bull. 946–D, pp. 107 and 111. 1945.
16. Johnston, W. D., Jr. and de Vasconcellos, F. M., Scheelite in northeastern Brazil, Econ. Geol., v. 40, pp. 37–40, 43–50. 1945.
17. Hobbs, S. W. and Clabaugh, S. E., Tungsten deposits of the Osgood Range, Univ. of Nevada Bull., v. 40, No. 5, pp. 13, 20, 21. 1946.
18. Lindgren, W., A suggestion for the terminology of certain mineral deposits, Econ. Geol., vol. 17, pp. 292–294. 1922.

U. S. Geological Survey,
Washington, D. C.,
February 22, 1947.

THE METALLIFEROUS GEOCHEMICAL ZONES OF AUSTRALIA.

E. SHERBON HILLS.

CONTENTS.

	PAGE
Abstract	478
Introduction	478
Factors Influencing a Zonal Distribution of Elements at the Earth's Surface	479
Factors Influencing Geochemical Zoning	479
Copper	480
Gold	484
The Metallogenetic Provinces	484
Elements other than Copper and Gold	484
Appendix	490

ABSTRACT.

Spot maps showing recorded occurrences of minerals containing certain elements as essential or important constituents have been prepared, in an attempt to discover and delimit the main metallogenetic provinces of Australia. Correlation with geological events is clear in a broad way, and it is shown that in Paleozoic and later times there has been a progressive shift in the location of successively developed ore-zones from west to east in eastern Australia.

INTRODUCTION.

In considering possible ways of extracting data on the geochemical zoning of Australia from existing information, it occurred to me that spot maps showing the distribution of all recorded occurrences of mineral species that contain a particular metal as an "essential" or important constituent, might have some significance for selected metals. It was originally hoped that concentration-contours of the spots might be made, but although there is probably a good deal to be learned from such contouring, it became clear, firstly, that to be of value for such an approach the maps would need to be on a much larger scale than that selected—the originals are on a scale of about 100 miles to an inch; secondly, that recorded knowledge of mineral occurrences in Australia are far from adequate for this purpose; and, finally, that the spot maps themselves, in spite of their deficiencies, reveal many important regional relationships in the distribution of the metallic constituents of ore minerals. The properties of the map projection used are not significant for the descriptive treatment finally adopted. In this treatment, elements such as iron and aluminum, which are important constituents not only of many rocks but also of their weathering products, and may be reported as ore deposits in the latter condition, could clearly not be dealt with; nor does the method take account of disperse occur-

rences of the metals selected, as minor or trace constituents. Even for definite mineral occurrences, the number of localities recorded in any mining field is of course many times smaller than the actual number of surface occurrences. Lack of data due to inadequate exploration and reporting also affect the reliability of the method, but much of Australia has by now been studied with sufficient thoroughness to reveal the over-all picture of distribution with some degree of clarity. Indeed, the susceptibility of the results to correlation with geological and tectonical data is a good indication that they are significant.

FACTORS INFLUENCING A ZONAL DISTRIBUTION OF ELEMENTS AT THE EARTH'S SURFACE.

A full discussion of geochemical zoning is not intended herein, but in order to place the work in correct perspective, the factors influencing a regional preferential distribution of elements at the earth's surface (other than subjective factors affecting discovery or research) are briefly summarized below. The question is immediately raised, however, as to whether the regional preferential distribution of mineral species revealed in the present work is or is not an indication of differences in bulk composition of the crust in the various regions. It may merely indicate that the crystalline mineral have been segregated to different degrees in different regions from a previously dispersed state and from source materials that might have much the same average composition in all the regions concerned. It is, however, convenient in the first analysis to regard the mineral occurrences as indicative of geochemical zones.

Factors Influencing Geochemical Zoning.

A. Igneous Rocks, and Ore Deposits of Magmatic Origin.—(a) Possible existence of geochemical provinces in deep-crustal or sub-crustal layers supplying magma or transfusing fluids.

(b) Processes of differentiation on a regional scale leading to differences in quantitative distribution of elements from homogeneous source-material.

(c) Zonal distribution of igneous rocks and ore bodies, due to physical causes, *e.g.*, tectonic control or pressure-temperature zoning.

(d) Possible influence of country-rocks through lateral secretion, assimilation, or palingenesis. This would be a reflected or mimetic zoning due to a pre-existing differential distribution of elements.

B. Sedimentary Rocks.—It would clearly be possible to treat the outcrop-pattern of sedimentary rocks of different mineralogical constitution as an instance of geochemical zoning, but the more intimate chemical details of organic and inorganic sediments, especially with regard to the occurrence of minor constituents, have also to be considered, so that a full treatment would be closely analogous to that for rocks of igneous origin.

No systematic account of sedimentary rocks will be atteempted herein, but mention may be made of David's reference (5) [1] to a phosphate-rich zone in the Upper Ordovician of eastern Australia extending from Victoria to southern Queensland; to the sedimentary iron ores of the Pre-Cambrian, and to the

[1] Numbers in parentheses refer to Bibliography at end of paper.

strontium and barium occurrences in the Cretaceous rocks of South Australia and south-western Queensland.

C. Metamorphic Rocks.—Since metamorphic diffusion is apparently local in its effects, geochemical zoning of metamorphic rocks would be largely of the mimetic type, apart from the effects of materials added in injection gneisses and diabrochites (6).

D. Weathering, erosion, folding, faulting and the deposition of covering rocks affect the delineation of geochemical zones at the earth's surface, but are not fundamental to the problem.

Combination of the above-mentioned factors would lead to great complexity, and the present study is only a preliminary stage in the analysis for Australia. The following remarks are directed to the maps that are given for each element discussed.

Copper.

Among the selected elements, copper and gold are notable for their widespread occurrence in all the metalliferous regions. It is therefore convenient to use them in delimiting the metallogenetic provinces, and in correlating these with geological and tectonic data, as has been done in Fig. 1.

In a broad view, we may distinguish between occurrences on the Australian Shield and those lying in the region east of the shield. The eastern limit of the shield, as shown in Fig. 1, is based on a tectonic analysis previously made by the author (8).

Zones East of the Australian Shield.—Here can be recognized firstly the important copper belts of South Australia and the Cloncurry-Mt. Isa district of western Queensland. In South Australia this zone has, I believe, a sharply-defined western margin beyond which, although Pre-Cambrian rocks occur, copper minerals are lacking, except for sporadic occurrences such as are typical of the shield area farther west. The cartographic eastern margin is affected by Tertiary covering rocks. Mineralization in this belt is of uncertain age, many of the occurrences being situated in Pre-Cambrian rocks; but some (*e.g.*, Sliding Rock Mine) are in Cambrian limestones and the period of ore genesis is tentatively placed as late Proterozoic to Lower Paleozoic. The Cloncurry-Mt. Isa copper belt is also mainly in Pre-Cambrian rocks, but Cambrian limestones in places carry quartz reefs, and one copper lode is in Cambrian rocks west of Mt. Isa, although this may possibly be of secondary origin. Between the Queensland and South Australian occurrences, younger deposits of the Great Artesian Basin cover the Pre-Cambrian and Lower Paleozoic rocks, but there seems good reason to suggest that in the intervening area the two belts would be linked. The tectonic analysis previously made (8) also suggested the linkage of these two belts, which are regarded as marking the eastern edge of the Australian Shield.

To the west of the Cloncurry-Mt. Isa belt, the Pre-Cambrian rocks are overlain by flat-lying Cambrian sediments on the Barkly Tableland, and it might be suggested that the existence of the metalliferous belt is due simply to the accident of exposure of the Pre-Cambrian terrain between the Barkly Tableland and the Great Artesian Basin (Fig. 1). On the other hand, as

the copper belt is approached from the west the Cambrian rocks become increasingly disturbed, and are folded and bear quartz veins in the Lawn Hills mineral field. The western margin of the belt is therefore regarded as a tectonic (and geochemical) boundary.

East of the copper belt, mineralization is believed to be Pre-Cambrian and older than Upper Proterozoic in the Broken Hill district of New South Wales, but, with the possible exception of some occurrences of doubtful age in north Queensland, all the other copper deposits in eastern Australia are Paleozoic or Mesozoic.

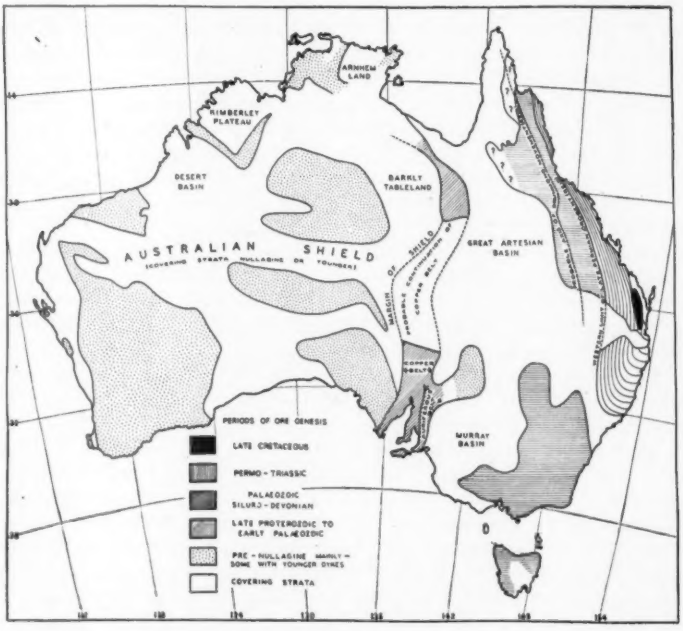


FIG. 1.

There can be recognized firstly an older Paleozoic (post-Ordovician, pre-Carboniferous) province of Victoria and New South Wales, the northerly continuation of which is hidden in south Queensland by the rocks of the Great Artesian Basin. In northern Queensland, however, a pre-Carboniferous ore zone is also found including the Mt. Coolon, Kangaroo Hills, Herberton, Chillagoe, and Etheridge mineral fields. The axis of this zone corresponds in large part with the tectonic line called by Reid (11) the "Axis of the Drummond Movement."

More detailed analysis of the Paleozoic ore zones of eastern Australia will

LIBRARY SEP 9 194 MANHATTAN

eventually be possible, but it is not desired to enter here on such a discussion, which would have a considerable content of controversial matter.

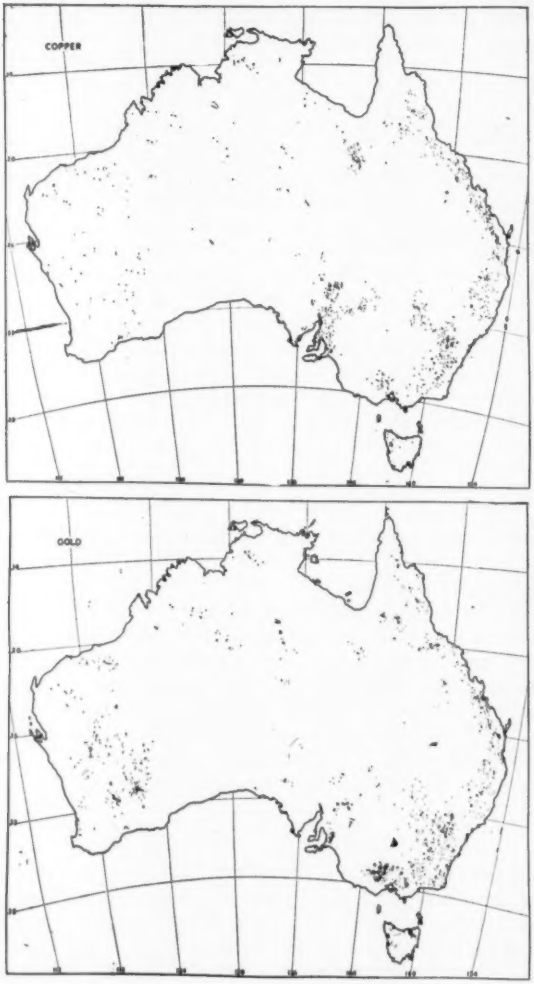
Along the east coast of Queensland and in the New England district of New South Wales, a Permo-Triassic province is very clearly defined (compare Figs. 1 and 2). Its western limit is in places sharply marked and follows the line shown by Reid (11) as the limit of late-Permian strong folding. The ore deposits in this region are associated with granitic and genetically related intrusives, the age of which is epi-Permian to Triassic. West of the limiting line of strong folding, Permian rocks are gently folded or tilted, as in the Bowen-Dawson coal-field of Queensland and the Newcastle-Bulli coal-field of New South Wales. Continuation of the Permo-Triassic belt northwards beyond the line marking the limit of strong Permian folding shown by Reid is indicated by the reported Permian age of tin, tungsten and molybdenum deposits at the Annan River and Mt. Carbine in far nothern Queensland.

Folding of Cretaceous rocks in the east-coastal district of Queensland between Bundaberg and Yandina is stated in a recent paper by Bryan and Jones (3) to be associated with late-Cretaceous intrusions of granite, syenite and diorite. Gold, copper, antimony and possibly mercury ores were introduced, these constituting the youngest suite of ore deposits of magmatic origin in Australia.

The eastern or cordilleran copper-bearing zone of the continent is thus seen on analysis to be a complex of ore deposits of Paleozoic and Mesozoic age, the heterogeneity of which may be contrasted with the more recent Tertiary and Quaternary unity shown by the Eastern Australian Cordillera in its physiographic development, as has been emphasized by E. C. Andrews (1910).

The Australian Shield.—On the shield there is a great unconformity between the late Proterozoic Nullagine rocks or their equivalents, and the older Pre-Cambrian. With few exceptions, the metalliferous ore bodies in the shield area lie in the latter rocks and are believed to be genetically connected with granitic and other intrusions of pre-Nullagine age. That many of the ore deposits situated in the older Pre-Cambrian rocks are in fact pre-Nullagine is quite clear but, as has recently been clearly pointed out by Bowley (1), there are numerous occurrences of copper, lead, zinc and silver in Western Australia connected with basic dikes that either intrude Nullagine rocks or are similar to the very numerous basic dikes that do so. As the author has recently indicated, these dikes are very possibly Paleozoic (1946). Their pattern suggests a fracture system which spreads over most of Western Australia and may well have affected the whole shield. Since, too, there are many similar dikes in the mobile zone east of the shield it may ultimately be possible to show some genetic relationship between certain of these and the post-Nullagine dikes in the shield.

In a broad view, copper occurrences in the shield area are seen to be sporadic in their distribution. If a rough attempt is made to gauge the importance of the pre-Nullagine copper mineralization by excising certain occurrences known to be connected with the later dikes (*e.g.*, Northampton, Ravensthorpe in part, etc.), the spare copper mineralization of the older rocks becomes even more obvious. Again, most of the larger producing fields in Western Aus-



FIGS. 2a AND 2b.

tralia are associated with the later dikes, so that the older deposits are not only sporadic but of very minor economic importance. There is no producing field in any part of the shield comparable with the major centers in eastern Australia, even including those connected with the dikes, such as Northampton.

Gold.

The distribution of gold shows a close similarity to that of copper as regards both location and age of the occurrences, but there are noteworthy differences in mass-concentration. Thus the important Western Australian goldfields are poor in copper, and similarly the Paleozoic ore suites in Victoria are rich in gold but poor in copper; but in South Australia the copper belt is associated with valuable gold deposits. Here, however, the auriferous zone is restricted to the eastern margin of the copper belt. The reasons for this are unknown, but the reality of the phenomenon is assured by the fact that gold is economically sought after down to small concentrations that might be expressed in geochemical units say, one part in 100,000. Zonal variation in distribution is already known in connection with the gold occurrences in Victoria where H. L. Wilkinson and others have recognized the main auriferous belts of the State, and for purposes of geochemical research it may be suggested that the gold would be an excellent subject for more detailed study. (See Fig. 2).

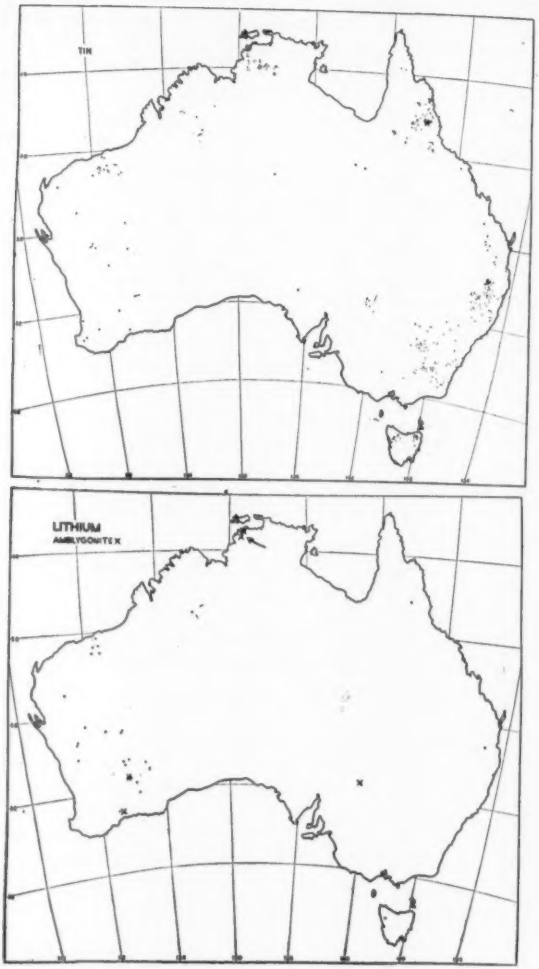
The Metallogenetic Provinces.

The metallogenetic provinces of Australia are represented in Fig. 1, in which, however, the occurrences related to post-Nullagine dikes in Western Australia are not differentiated.

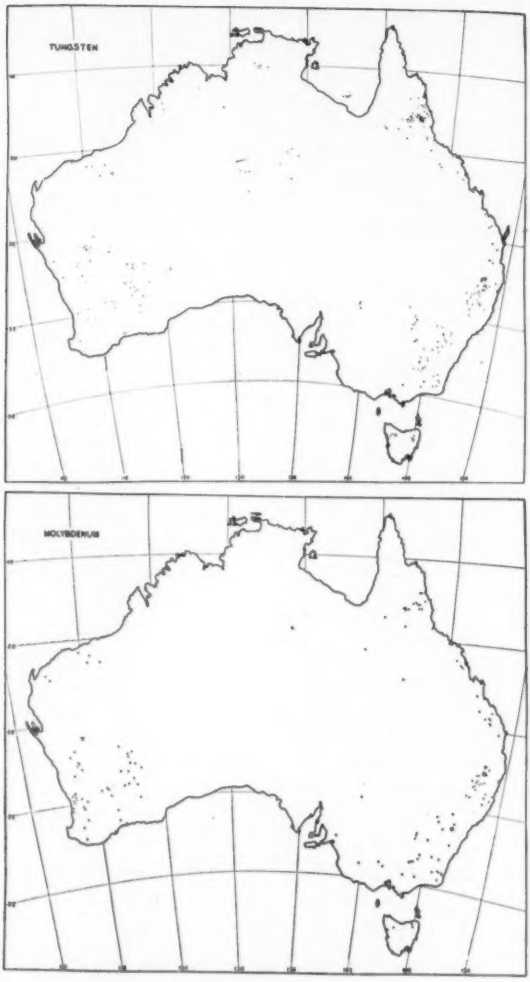
In a broad view of the various suites, the chief occurrences of ore minerals in Australia are progressively younger from west to east, the shield occurrences being pre-Nullagine, those of the South Australian-western Queensland belt late Proterozoic to early Paleozoic, those of the next belt (covered over large areas by younger rocks) post-Ordovician and pre-Carboniferous, and those of the main east-coastal belt in Queensland and New England epi-Permian to Triassic. The youngest so far recorded lies in the farthest easterly extension of Australia, in the Bundaberg district, and is late Cretaceous.

Elements Other Than Copper and Gold.

Certain of the geochemical characteristics of the above-mentioned zones are shown in the variations in the distribution of elements other than copper and gold. It has been found that a zone or part of a zone may be barren for a particular element, or may possess it only sporadically. It has been shown, for instance, that in the South Australian copper belt, gold is restricted to an eastern sub-zone of the belt. It is further noteworthy that in both the South Australian and western Queensland copper belts, tin, tungsten, molybdenum, tantalum, lithium, and mercury minerals are either not recorded at all or are of extremely rare occurrence. In these belt lead shows a closely similar distribution to gold, but zinc appears to be rare. (Figs. 3–6).



FIGS. 3a AND 3b.



FIGS. 4a AND 4b.

The possession of similar geochemical characteristics by both the South Australian and western Queensland copper belts supports the suggestion that they belong to the same mineralized zone, and that the connection between them has been obscured by later rocks.

As would be expected, mercury is preferentially located in the younger ore provinces of eastern Australia where erosion has presumably not removed the upper thermal zones, but its presence at a few localities in the shield is to be noted. By way of contrast, tantalum occurs, as David (5) has previously noted, perhaps exclusively in Pre-Cambrian ore bodies—the age of the north Queensland occurrences being uncertain—and lithium minerals are likewise characteristic of the shield, and extremely rare in the eastern ore zones.

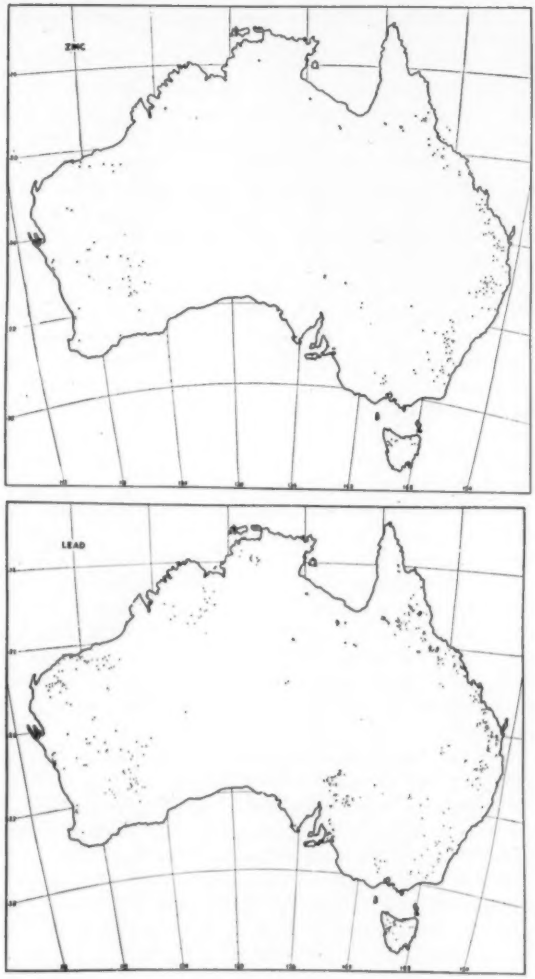
It is notable, moreover, that every one of the mineral constituents dealt with occurs in the older Pre-Cambrian rocks of the shield (although it must be noted that these rocks are distinctly poor in copper, lead, and zinc), but that in the eastern zones of the continent certain elements as mentioned above are either absent or very rare. The elements of rare occurrence in the eastern cordilleran zone include tantalum, lithium, and beryllium, which will be recognized as having some family affinity from the point of view of ore genesis.[2] This suggests as a first hypothesis that the underlying causes of the difference in distribution are connected with geological events rather than with a fundamental geochemical distinctiveness of the shield as contrasted with the eastern cordillera, but the topic requires further study.

The relative paucity in all ore minerals of the east-west striking Pre-Cambrian rocks in Central Australia is also noteworthy. It has been pointed out also by de Courcey Clarke (4) that in the so-called Median Belt of Western Australia between the Pilbara and Central goldfields, east-west strikes prevail and ore deposits are few and of little value. In this connection it is interesting to recall the old controversies in which Murchison and the Rev. W. B. Clarke were involved, centering about Humboldt's generalization that gold occurs preferentially in rocks striking generally north-south rather than east-west. Letters from Murchison to Clarke on this subject are quoted in Jervis' biography of Clarke (9).

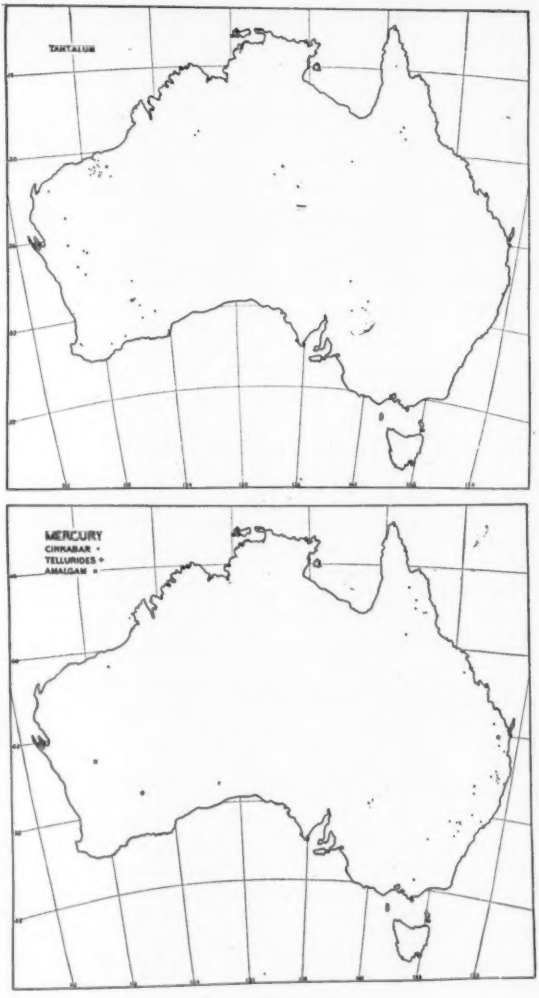
Finally, some important points requiring further investigation may be mentioned. If we accept the view lately restated by Bryan that the former eastern margin of the Australian continental block lies along the edge of the Pacific basin proper (from New Zealand to Fiji) then all the orogenic zones of eastern Australia presumably involve Pre-Cambrian rocks in depth. Similarly each younger orogen has presumably involved rocks of an older orogen in part at least, so that conceivably the younger intrusives could by various known mechanisms derive all or part of their substance from pre-existing rocks and ore bodies.

Until much more is known, on a basis of complete analyses of minerals and rocks selected to test the variety of working hypotheses that might be propounded to account for the regional distribution of ore minerals, it would not, I think, be possible to present reliable figures for the average composition of rocks or of the crust in Australia. During the segregation of minerals into

[2] For example, see Niggli (10) on the sequence of separation of ore minerals.



FIGS. 5a AND 5b.



FIGS. 6a AND 6b.

an ore body the source material is impoverished, and to what extent the composition of a rock may have been affected by such losses or by the addition of material from another source would be difficult to determine in many instances. Comparison of the relatively barren older Pre-Cambrian rocks of Central Australia with the highly mineralized areas in Western Australia would be of interest in this connection.

In conclusion, and as an indication of the possible wider application of geochemistry to geological problems such as that of Continental Drift, the notable distinctions between Peninsular India and the Western Australian Shield as regards mineral deposits may be pointed out. Peninsular India lacks important deposits of tin, tungsten, molybdenum, tantalum and lithium, the ores of all of which are present, with many others, in those parts of Australia with which India is represented on Wegener's maps as having been in contact. On du Toit's reconstructions of Gondwanaland (7), however, Antarctica is interposed between India and Australia, which is more satisfactory from the geochemical viewpoint.

UNIVERSITY OF MELBOURNE,
MELBOURNE, AUSTRALIA,
May 12, 1947.

REFERENCES.

1. Bowley, H., 1945, The Mineral Resources of Western Australia, 5th Ed., Dept. Mines, Western Australia.
2. Bryan, W. H., 1944, The relationship of the Australian continent to the Pacific Ocean—now and in the past, Jour. Royal Soc. New South Wales, Vol. 78, pp. 42–62.
3. Bryan, W. H., and Jones, O. A., 1946, The geological history of Queensland, Univ. of Queensland Papers, Vol. 2 (new ser.), No. 12.
4. Clarke, E. de C., 1938, Middle and west Australia; in Regionale Geol. d. Erde, Leipzig.
5. David, T. W. E., 1932, Explanatory notes to accompany a new geological map of Australia, Sydney.
6. Dunn, J.A., 1942, Granite and magmation and metamorphism, ECON. GEOL., Vol. 37, No. 3, pp. 231–238.
7. du Toit, A. L., 1937, Our Wandering Continents, Edinburgh, Oliver and Boyd.
8. Hills, E. S., 1946, Some aspects of the tectonics of Australia, Jour. Royal Soc. New South Wales, Vol. 79, pp. 67–91.
9. Jervis, J., 1945, Rev. W. B. Clarke, M.A., F.R.S., F.G.S., F.R.G.S., Roy. Australian Hist. Soc., Sydney.
10. Niggli, P., 1929, Ore-deposits of Magmatic Origin, London, Murby and Co.
11. Reid, J. R., 1930, The Queensland Upper Paleozoic succession, Queensland Geol. Survey Pub., No. 276.

APPENDIX.

Notes on the Figures

The chief sources of information concerning mineral occurrences, used in preparing the maps for this paper, are the numerous compilative works published by the State and Federal geological and mining authorities. Other reliable sources have also been used, but no useful purpose could be served by listing them all. For gold in Victoria, the individual dots have been inserted to cover the known auriferous zones rather than to indicate particular localities, and an arbitrary variation in spacing indicates the relative intensity of mineralization. I am indebted to Miss Beryl Langham for considerable assistance in the compilation of data. The following are the major sources of information used:

Victoria

Selwyn, A. R. C., and Ulrich, G. F. H., 1866, Notes on the physical geography, geology and mineralogy of Victoria, Intercolonnial Exhibition Essays.

Centennial International Exhibition, A descriptive catalogue of rocks, minerals and fossils, Dept. of Mines, Victoria, 1888.

Kitson, A. E., 1906, The economic minerals and rocks of Victoria, Special Report, Dept. of Mines, Victoria.

New South Wales

Pittman, E. F., 1901, Mineral resources of New South Wales, Geol. Survey New South Wales.

Tricket, O., 1919, Bibliography of the economic minerals of New South Wales, New South Wales Dept. of Mines, Min. Res. No. 28.

Liversidge, A., 1888, Minerals of New South Wales, Trubner & Co., London.

Queensland

Dunstan, B., 1914, Queensland Mineral Index, Queensland Geol. Survey, Pub. No. 241.

South Australia

Brown, H. Y. L., 1908, Record of the Mines of South Australia, 4th Edition, by authority, Adelaide.

Western Australia

Carroll, D., 1945, Census of West Australian minerals, Bull. No. 1, Mineral Res. Western Australia.

Tasmania

Petterd, W. F., 1910, Catalogue of minerals of Tasmania, Dept. of Mines, Tasmania.

Northern Territory

Bulletins of the Northern Territory, Home and Territories Dept., Melbourne.

Reports on Explorations, published as South Australian Parliamentary Papers.

Reports of the Northern Australian Aerial Geological and Geophysical Survey, by authority, Canberra.

AN EOLIAN DAM NEAR TUCUMCARI, NEW MEXICO.

E. DOBROVOLNY AND R. C. TOWNSEND[1]

ABSTRACT.

Surface drainage of Tucumcari Lake east of Tucumcari, New Mexico, is dammed by eolian sand derived from the Wingate (?) sandstone. Evidence for this is: (1) the character and age of the material making up the dam; (2) evidence of subsurface drainage; (3) the lithologic similarity of the material in the dam only to the Wingate (?) sandstone; (4) prevailing wind direction and intensity; and (5) the presence of active dunes in and near the Tucumcari area.

The lake probably will not serve as a satisfactory natural reservoir site because of subsurface drainage through the eolian dam.

INTRODUCTION.

THE intermitttent Tucumcari Lake, just east of the city of Tucumcari in northeastern New Mexico, has no subsurface drainage, and at one time it was considered a possible natural reservoir site. Detailed study indicates that the lake drains through sands that act as a barrier on the north side of the basin. It is thought that the material confining the lake on the north is eolian sand which was deposited as a large low dam across what was formerly a shallow valley.

Background information was obtained in the summer of 1945 when the area between the Canadian River and the Llano Estacado escarpment was mapped in connection with the U. S. Geological Survey program of oil and gas investigations. The geology of the vicinity of Tucumcari as shown in Fig. 1 is slightly modified from "Geology of northwestern Quay County, New Mexico."[2] In October 1946, more detailed investigations were made and samples were collected for petrographic study.

Mr. Murel M. Starr, project engineer of the U. S. Bureau of Reclamation, kindly provided detailed topographic contour maps and supplied logs and samples from hand-drill holes made by the Bureau of Reclamation in their subdrainage studies. Mr. Donald R. Burnham of the U. S. Department of Agriculture Experiment Station provided corroborative information relative to prevailing wind direction.

TOPOGRAPHY.

Tucumcari Lake occurs in a topographic basin which is about 15 square miles in area. The basin is bounded on the east and southeast by level uplands, on the southwest by dissected uplands, and on the west by a narrow ridge. Beyond the narrow ridge Pajarito Creek (Intermittent) flows in a

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Oil and gas investigations, preliminary map 62, 1947, "Geology of northwestern Quay County, New Mexico," by E. Dobrovolny and C. H. Summerson.

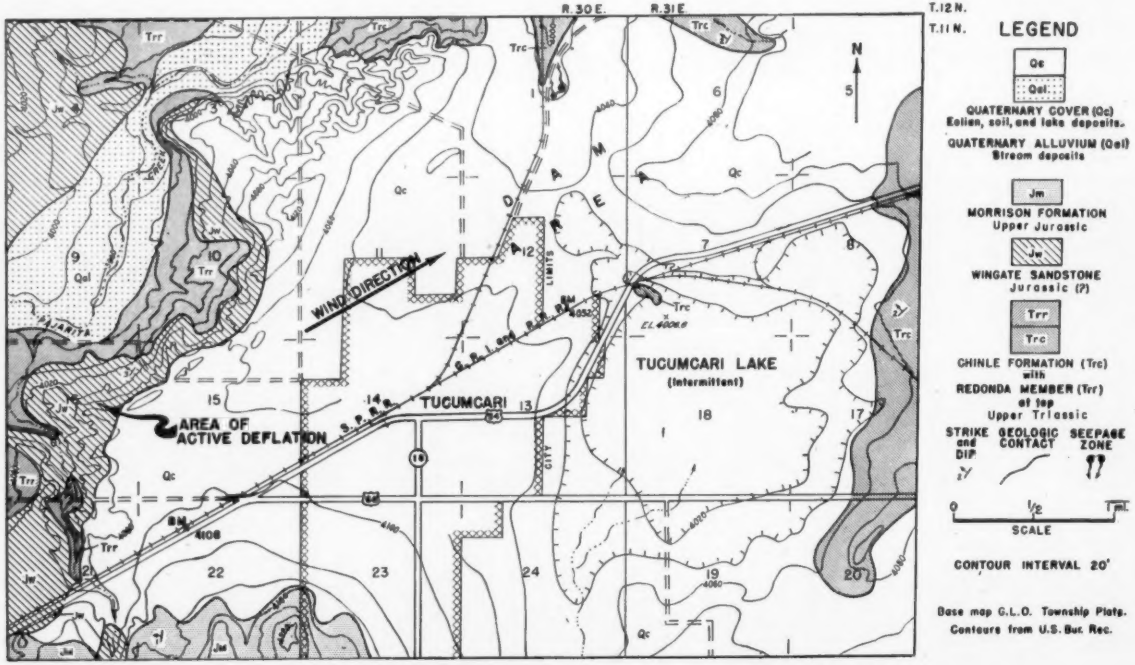


FIG. 1. Geologic and topographic map of the vicinity of Tucumcari, New Mexico.

northerly direction. Between this ridge and the uplands to the east is a relatively low, flat area (see dam area, Fig. 1), which defines the basin on the north. This low barrier to northward surface drainage from Tucumcari Lake is only 40 feet higher than the lowest point in the lake, which has an elevation of 4,006.6 feet. North of the dam area, drainage is to Pajarito Creek.

The area of the lake is about 500 acres when the water level is 4,010 feet in elevation. Eighty percent of the water in the basin enters the lake by north and northwest trending streams.

DESCRIPTION OF FORMATIONS.

The outcropping rocks in the vicinity of Tucumcari are of Triassic, Jurassic, and Quaternary age. The exposed Triassic rock is the Chinle formation which is separated into two units: a lower unnamed unit and the overlying Redonda member. The lower unit contains dark-red, slightly sandy shale and minor red and gray sandstone. It is overlain by the Redonda member consisting of buff to pink siltstone, variegated shale, fine sandstone and minor lenses of purplish to red clayey limestone and silty shale.

The Jurassic rocks are the Wingate(?) sandstone and the Morrison formation. The Wingate(?) sandstone, which unconformably overlies the Chinle formation, is friable, red and white, medium- to fine-grained, and cross-bedded. The Wingate(?) sandstone is readily subject to wind erosion because of its poor cementation and its grain size. This sandstone caps the ridge to the west of the basin; the eastern boundary of the formation, as shown on Fig. 1, is difficult to define because it is obscured by dune sand eroded from the same standstone.

The Morrison formation overlies the Wingate(?) sandstone, and is divided into three members, only the lower two of which may be seen in the area shown in Fig. 1. The lowest member is alternating green and red shale, and interbedded sandstone that contains irregular fragments of red chalcedony. The middle member consists of red, green and purple shale and speckled gray sandstone.

In this area the average dip of formations older than Quaternary is about 2° to the west.

EVIDENCE POINTING TO EOLIAN ORIGIN.

It is believed that Tucumcari Lake is dammed on the northeast by wind-blown sand derived from the Wingate(?) sandstone. This is based on: (1) the character and age of the material making up the dam; (2) evidence of subsurface drainage of the lake; (3) the lithologic similarity of the material in the dam only to the Wingate(?) sandstone; (4) prevailing wind direction and intensity which indicate that the Wingate(?) sandstone is the source of material in the dam; and (5) the presence of active dunes in and near the Tucumcari area.

Character and age of dam.—The material is unconsolidated, unsorted, fine sand and silt deposited in Quaternary time (Table 1). Such material might easily be wind-deposited. The pattern of the contours shown on Fig. 1 indi-

cates that if the dam were not present, the basin would be part of a northward draining valley. The drainage system in the basin is anomalous to the extent that normal drainage prevails in areas adjacent to the basin.

Subsurface drainage.—The lake bed is in the impervious Chinle formation, and if it were not for evidence of subsurface drainage, a ridge of this formation might be assumed to be damming the lake.

Imperviousness of the Chinle in this area is indicated in several ways besides its fine-grained nature as shown by microscope study (Table 1). The Chinle formation in the vicinity of Tucumcari Lake is essentially a structureless shale with minor disseminated sand grains. Auger holes were dug several miles west of the area outlined in Fig. 1, and located in approximately the same stratigraphic position as the Chinle exposed near the lake. These holes were filled with water and the water level was found to lower less than one inch in 24 hours. The loss was therefore attributed to evaporation and the material was considered impervious.

Evidence of subsurface drainage through the dam is not lacking. Intermittent lakes without subsurface drainage occuring in the Triassic beds of

TABLE I

COMPARISON OF GRAIN SIZE, GRAIN SHAPE, AND MINERAL CONTENT OF CRITICAL FORMATIONS

	Grain Size	Grain Shape	Minerals
SAND FROM DAM AREA	Approximate grain size range, 0.25 and 0.01 mm. Generally finer than Wingate(?) sandstone but coarser than Chinle 15% below 0.01 mm.	Subangular to rounded Small grains partly rounded	Mostly quartz, coated by hematite. Others—1 to 3%: gypsum muscovite(?) pyrite garnet tourmaline inclusions in quartz
WINGATE(?) SANDSTONE	Approximate grain size range, 0.4 and 0.01 mm. Fines absent	Subangular to rounded Small grains mostly subangular	Mostly quartz, coated by hematite. Others—4 to 7%: microcline orthoclase calcite magnetite pyrite titanite tourmaline inclusions in quartz
CHINLE FORMATION	Very fine grained, composed largely of grains smaller than 0.1 mm. Clusters of clay minerals Well graded from maximum to minimum size	Angular grains	Quartz, coated by hematite. calcite, mica, orthoclase, microcline } Large Amounts clay minerals(?) abundant

this area are commonly saline. No residue of salts is present when Tucumcari Lake is dry, and the lake bottom is covered with a lush growth of vegetation, further indicating the absence of salts. North of the dam area, in the north half of section 1, at an elevation near 4,010 feet, is a seepage zone covering approximately two acres. Seepage occurs only when water is present in Tucumcari Lake. When Tucumcari Lake is dry the seepage zone is also dry. This indicates that the seepage zone is the surface expression of drainage from Tucumcari Lake.

Lithologic similarity to Wingate(?) sandstone.—The sand in the dam area north of Tucumcari is strikingly similar to the sand of the Wingate(?) sandstone.

Samples were collected from (1) the Wingate(?) sandstone exposures along Pajarito Creek; (2) from the bottom of cuts along the Southern Pacific Railroad in section 12, T. 11 N., R. 30 E.; (3) from several 12-foot drill holes in sections 1 and 12, T. 11 N., R. 30 E.; section 7, T. 11 N., R. 31 E.; (4) from the Chinle formation exposures east of the highway underpass in the southwest part of section 7, T. 11 N., R. 31 E.; and (5) from the Chinle formation along U. S. Highway 54 in section 8, T. 11 N., R. 31 E. Microscopic study shows that the sand grains of both the Wingate(?) sandstone and the dam area are rounded to subangular and are coarser than the sand particles of the Chinle formation. The Chinle formation contains large amounts of calcite, mica, orthoclase, and clay minerals, but in the Wingate(?) sandstone as well as in the migrating sands north of Tucumcari these minerals are present in minor amounts or absent (Table 1). Wingate(?) sandstone is suggested as the main source of material composing the eolian dam.

Wind direction, intensity, and active dunes.—The persistence of moderately strong winds is a notable climatic feature of this region. The prevailing wind direction as determined from active dunes and from row crop information provided by the U. S. Department of Agriculture is N. 60° E. Agriculture has tended to obscure evidence of dune migration in the area immediately north of Tucumcari. Immediately northeast of the area mapped, however, sand dunes are so active that farm sites have been enveloped. The prevailing wind direction was measured on aerial photographs which show stages of dune migration in a constant direction.

The process of deflation can be observed directly at a large exposure of Wingate(?) sandstone southeast of Pajarito Creek. It may be seen on Fig. 1 that the Wingate(?) sandstone is probably the source of the material in the dam area.

CONCLUSION.

Tucumcari Lake originated when migrating sand formed a barrier across the shallow valley. Most of the material came from the Wingate(?) sandstone deposits east of Pajarito Creek. North-flowing tributaries now ending in Tucumcari Lake were once connected with Pajarito Creek by the southward heading stream located in section 1, T. 11 N., R. 30 E. In forming the eolian dam, sand migration was not necessarily rapid, but material was laid down in greater volume than could be removed by the stream connecting Tucumcari

Lake basin with Pajarito Creek. The impervious beds composing the Chinle formation confine the subsurface drainage from Tucumcari Lake to the pervious sands which fill the old channel and permit the water to come to the surface in a zone of seepage.

The land north of Tucumcari will probably have good subsurface drainage because of the pervious nature of the wind-blown material. "Souring" of the land resulting from upward migration of salts is not anticipated.

Because of subsurface drainage Tucumcari Lake will not serve as a satisfactory natural reservoir site. The area that is intermittently covered by water is probably good agricultural land, but the problem of providing drainage rapid enough to eliminate flooding might be economically impossible.

U. S. GEOLOGICAL SURVEY,
BOX 2858, LAKEWOOD BRANCH, DENVER, COLO.,
May 5, 1947.

REVIEWS

Geology and Ground-Water Resources of the Island of Hawaii. By H. T. STEARNS and G. A. MACDONALD. Pp. 363; Plates 54; figs. 60. Bull. 9, Hawaii Division of Hydrography, Honolulu, T. H.

Students of volcanism everywhere will find this volume of interest and value. The diverse processes which have been active in the formation of the "Big Island" and the many rock types and land forms produced by volcanic processes and subsequent erosion are described in detail and illustrated by numerous line cuts and photographs.

"The fundamental concept of Hawaiian volcanism . . . is that the lavas are almost entirely erupted from narrow fissures confined to rift zones intersecting beneath the summit of each dome. . . ." The four principal phases are as follows: First, the youthful phase, in which a shield-shaped dome is rapidly built up over two major and one minor rift zones with a small crater at their intersection, and stream erosion is absent. Second, the mature phase, in which volcanism continues and gradual collapse produces a summit caldera and rift grabens; the part of the volcano shielded from lava accretions is eroded by streams and ocean. Third, the old-age phase, in which the calderas and grabens are obliterated as the volume of lava poured out exceeds the amount of collapse. Fourth, is the late rejuvenated phase, not closely related to the earlier phases, which is not seen on the island of Hawaii.

The older, more basic flows produce low volcanic mountains, whereas the younger, more acidic flows make steeper slopes. Further, volcanoes are strengthened in their maturity as dike swarms on the flanks solidify and divert extrusions to the summit area where magmas remains liquid longest.

Under "Geomorphology" are discussed the origin and characteristics of volcanic forms of subsidence, coastal fault scarps, stream erosion ("a measure of age on a volcanic island"), laval plains, glacial features, and other forms.

The rocks of Hawaii are almost entirely volcanic. These are largely basalt and andesite and small amounts of trachyte, and their intrusive equivalents. They range in age from Pliocene to Historic. The older rocks make up the bulk of the island but the younger are more in evidence. Volcanic activity is waning, and one younger series forming about 10 per cent of the mass of Mauna Kea above sea level may have required for its extrusion 25 per cent of the time since that volcano rose above sea level.

The geology of the five volcanoes, Mauna Kea, Kiluea, Mauna Loa, Kohala, and Hualalai, is discussed. More is known of Mauna Loa than of some of the others; its history may be briefly summarized as follows: A maximum of 10,000 feet of basalts was laid down in Pliocene time, after which erosional forces cut canyons as much as 4,000 feet deep. The Kahuku volcanic series, consisting of 600 feet of predominantly basaltic rock but including a maximum of 55 feet of ash at the top, was laid down in Pleistocene time. Deposition of the next series of rocks, the Kau volcanic series, began in latest Pleistocene time and has continued to be present. This series ranges in thickness from one flow on the lower

slopes to 600 feet on the walls of Makuaweoweo Caldera. The Kau (youngest) volcanics of Mauna Loa rose along fissures several miles long and from 1 to 10 feet wide and lie chiefly in three rift zones. The main structural elements of Mauna Loa are: (1) the three intersecting rift zones occupied by dike swarms, (2) the circular crater and caldera faults, (3) the rift faults, and (4) the coastal (subsidence) faults. Few generalizations may be made regarding periodicity of past eruptions and, aside from what may be based on seismic prelude data, little can be said in predicting future eruptions.

The description of the historic eruptions of Mauna Loa (and the summary of observed activity at Kiluaea) will undoubtedly be considered by many the most interesting portions of the volume.

Kiluaea, also active, is likewise discussed at length. Hualalai volcano, last active in 1800–1801, and Mauna Kea and Kohala Mountain are treated less exhaustively.

Regarding the chapter on petrography, particular mention may be made of the stratigraphic sections based largely on petrographic details. The principal factor is magmatic differentiation is ascribed to the sinking of, first, olivine crystals, and, later, augite and plagioclase crystals.

The rocks of the island are highly permeable and most of the rainfall sinks quickly into the ground. Most of this water sinks rapidly to the basal water table where it floats on sea water. A little is recovered in wells but so far most of the water escapes as springs along the coast.

Maui-type wells skim off this water. One such well at Ookala, which is 600 feet long on an incline of 30° from the horizontal, reaches a sump of 7 feet above sea level. A 15-foot tunnel from the sump leads to an 85-foot cross tunnel. The well yields 400,000 gallons a day with "slight drawdown." One other such well yields 2½ million gallons a day with 9 inches of drawdown, or 4½ million gallons a day with 11 inches of drawdown.

Basal ground water springs range from very small up to first magnitude (yielding more than 100 second-feet or 64.6 million gallons a day), as the spring near Hilo in Waiakea estuary discharges 146 million gallons a day. The Ninole spring in the Kau area discharges 20 to 25 million gallons a day. Most basal spring water contains significant amounts of chloride, especially near the coast, and much of it is not potable.

Important quantities of water are obtained from high levels where it is held by dike complexes. In Kohala Mountain the dike area is 6 miles wide and 14 miles long and ranges from 300 to 1,700 feet above sea level. With 13 to 24 inches of rain per month, the dike reservoir gains in storage and discharges up to 36 million gallons a day. With less rain, storage and discharge diminish but the discharge has not fallen below 23 million gallons a day. High-level water is recovered from streams, springs, and tunnels and, in places, is brought down by flumes.

Ground water also occurs perched on ash beds, inter-flow soil beds and, more rarely, on dense lava flows. Some of this water is recovered from springs but the most important and certainly most elaborate method of capturing such water is by driving a sinuous tunnel following a perching bed. One such tunnel, at an altitude of 3,097 feet, is 7,048 feet long and yields 1,286,000 gallons of water a day. Another tunnel 3,839 feet long obtains 713,000 gallons of water a day but the greatest yield, 5 million gallons a day, is obtained from a tunnel only 2,000 feet long.

It is estimated that only about 327,500,000 gallons a day, or 2.5 per cent of the rainfall, is visibly discharged from wells, tunnels, and springs. Many areas

favorable for large-scale exploitation of basal ground water by wells and tunnels are pointed out.

The volume is well illustrated with small maps, cross-sections, diagrams, and sketches, and contains 107 photographs in addition to a full color frontispiece.

The geologic and hydrologic features stand out clearly on the large multicolored geologic and topographic map, which is of the same high degree of excellence as maps accompanying the earlier volumes of the series.

Plate 2 contains a large sketch map of the island on heavy paper (presumably prepared by J. Y. Nitta), with an itinerary of points of geologic interest and accompanying explanations.

D. J. CEDERSTROM.*

Tungsten, Its History, Geology, Ore-Dressing, Metallurgy, Chemistry, Analysis, Applications and Economics. By K. C. LI, and CHUNG YU WANG. 2nd Edition. Figs. and charts. Reinhold Publishing Co., New York, April 1947. Price, $8.50.

The first edition of this book was widely received when it made its appearance in 1943. Those who know tungsten know the senior author, K. C. Li, and that he is the outstanding world authority on tungsten. His personal assistance was invaluable to the United States Government in meeting the tungsten problems during World War II and the first edition of this book was timely and helpful.

The volume is one of the series of Scientific and Technical Monographs sponsored by the American Chemical Society. This second edition has been considerably revised and enlarged, particularly with respect to the geology, applications, and alloys of tungsten. The manuscript has been gone over by such authorities as Zay Jeffries, E. A. Lucas, G. C. Wheeler, Frank L. Hess, and others.

K. C. Li, as a result of his training in England, was the discoverer of tungsten in China in 1915 and made the first shipments to the United States. Before Pearl Harbor he persuaded the U. S. Government to purchase all off-grade South American tungsten ore for processing in the United States in order to prevent its shipment to Germany and to make supplies available to us. He personally visited the South American mining districts and acquired for the U. S. Government all available tungsten ores and thus initiated the war imports of Latin-American tungsten ores.

The various chapter headings convey the contents: The History of Tungsten; Geology of Tungsten; Ore Dressing; Metallurgy; Chemistry; Analysis; Industrial Applications; Substitutions; and Economics. There are also four appendices on the Terms of purchase of Tungsten Ores, Chinese contracts, Post-war tungsten situation, and 7 pages of bibliography followed by an index.

To geologists the second chapter is of special interest. It contains a description of the deposits, their mineralogy, genesis, oxidation and weathering, secondary enrichment, classification, resources, and metallogenetic epochs and provinces. This is followed by descriptions of occurrences in each country. The mineralogy is illustrated by beautiful colored plates. The other chapters are each authoritative, complete and up to date.

The book is written in a nice easy style and will interest geologists, mining engineers, ore dressers, metallurgists, chemists, importers and economists.

* Published with permission of the Director, Geological Survey, U. S. Dept. of the Interior.

A Yanqui in Patagonia. By BAILEY WILLIS. Pp. 152; illus. Stanford Press, Stanford University, Cal., 1947. Price, $3.00.

In part this is an autobiography of this versatile geologist. His early life and his early association with the United States Geological Survey are treated in the first two chapters. The book then relates his interesting experiences from 1911 to 1915 as consulting geologist to the Minister of Public Works of Argentina. In his desire for colonization, the Minister requested the author to explore a remote lake and mountain region of the Andes where he investigated railway sites, lands and water power. This area is now a national park where Argentines resort for summer and winter sports.

This book, however, is not engineering; it is intimate, personal, and colorful autobiography. It deals with the country itself, with its politicians and patriots, and with the Americans, Latins, and gauchos with whom he rode and talked. He tells of the mountains, the forests and the trout-filled waters and he describes beauties of scenery comparable to Switzerland.

This book is as colorful as its author. It is beautifully printed and illustrated and is delightful and entertaining reading.

Texas Mineral Resources. By Bureau of Economic Geology, John T. Lonsdale, Director. Pp. 390; figs. 88; pocket of maps. University of Texas Publication No. 4301, Jan. 1943 (1946). Austin, Texas.

This volume is made up of 27 separate articles by individual authors, many of which are deserving of a full review in themselves. The articles and authors are: Principal war and industrial metals and minerals, by E. H. Sellards; Faulting in Houston County, by H. B. Stenzel; Mica, and Bird lead-silver mine, by R. C. Redfield; Gypsum in Edwards limestone, Soapstone, serpentine and feldspar in the Central Mineral Region, by Virgil E. Barnes; Grinding pebbles of Western Coastal plain, by G. A. Parkinson and V. E. Barnes; Barite, Celestite, Fluorspar, Diatomite, and Abrasive and Polishing Materials, in separate chapters, by Glen L. Evans; Stratigraphy of the Ellenburger Group, by P. E. Cloud, Jr., V. E. Barnes and Josiah Bridge; Devonian of Central Texas, by V. E. Barnes, P. E. Cloud, Jr., and L. E. Warren; Occurrence of oil and gas, by E. H. Sellards and Leo Hendricks; Subdivisions of the Ellenburger limestone in S. W. part of K. M. A. oilfield, by A. J. Crowley; Review of coal production, by H. B. Stenzel; Gypsum resources, Hockley Dome, by H. B. Stenzel; Manganese deposits, and Dolomite of Potter and Moore counties, by L. E. Warren; Limestone of Damon Mound, by E. M. Hurlbut, Jr.; Spiculite, Lampasas county, by H. G. Damon; Industrial sand from Eocene Rockdale formation, by E. C. Hoeman and R. C. Redfield; Texas water resources, by F. B. Plummer; Earth Temperatures and oil field waters of North-Central Texas, by V. E. Barnes; Index to Texas Mineral Resources, by E. H. Sellards and Glen L. Evans; Index.

This complete and well illustrated volume is a worthy companion to its well known predecessors.

BOOKS RECEIVED.

ALAN T. BRODERICK.

Géologie du Granite. E. RAGUIN. Pp. 212; figs. 46. Masson & Cie. Paris, 1946. *Well illustrated text on geology of granites and related rocks. Field relationships stressed. Some of the topics covered; constitution, structure, differentiation, the aureol, granitization and metamorphism, relationship with*

LIBRARY SEP 9 1947 MANHATTAN

orogeny and volcanism, metallogeny, radioactivity, problem of formation and emplacement.

As Formaçoes Geológicas mais Antigas da Orla Mesozóica Ocidental de Portugal. G. S. DE CARVALHO. Pp. 125; figs. 27. Doctor's dissertation, University of Coimbra, 1946. *Paleogeography and paleoclimatology as deduced from sedimentation studies of the West Mesozoic Border of Portugal.*

Union of South Africa Geological Survey Publications, Pretoria, 1940 to 1944.

Bull. 13 (1941). Tungsten Ores in South Africa with Special Reference to Namaqualand and the Orange River. G. K. JOUBERT. Pp. 8; map 1. *Brief account. Apparently contact metamorphic deposits of scheelite and wolframite. No estimate of reserves.*

Bull. 14 (1943). Fluorspar in the Union of South Africa and South West Africa. L. E. KENT, H. D. RUSSELL, D. P. VAN ROOYEN. Pp. 69; figs. 12; pls. 3. *750,000 tons reserves estimated in U. of S. Africa. Most deposits either low temperature fissure fillings in granite or replacements in the Dolomite series.*

Bull. 15 (1944). Waterberg Coalfield, Records of Boreholes 1 to 20 sunk for the Department of Mines. F. A. VENTER. Pp. 106. *Foot-by-foot geologic descriptions and bulk chemical, calorific, float and sink analyses.*

Memoir 38 (1942). Magnesite in the Union of South Africa. J. S. VAN ZYL, L. G. BOARDMAN, J. W. BRANDT, J. DE VILLIERS. Pp. 82; figs. 6; pls. 15. *Minor reserves of low-iron amorphous secondary magnesite in in near-surface veins in ultra-basic rocks.*

Memoir 39 (1944). Lead Deposits in the Union of South Africa and South West Africa with Some Notes on Associated Ores. J. WILLEMSE AND OTHERS. Pp. 186; figs. 40; pls. 23; tbls. 5. *Detailed descriptions 50 lead occurrences and associated Va and Zn deposits. Estimate 230,000 tons Pb available, largely in Tsumeb mine. Most deposits in dolomite under barriers. Ores believed derived from Bushveld igneous complex.*

Coal Survey Memoir 1 (1940). The Northern Natal Coalfield (Area No. 1). The Vryhend-Paulpietersburg Area, Part 1 (Geological) and Part 2 (Chemical and Physical). J. J. G. BLIGNAUT, F. J. J. FURTER, J. C. VOGEL. Pp. 336; figs. 50; pls. 16; maps; tbls. 48. *46,000,000 tons workable anthracite, 64,000,000 tons coking and 58,000,000 tons non-coking bituminous estimated in Middle Ecca strata. Many seams widely metamorphosed by Karroo dolerite sills. Report accompanied by one 1:125,000 colored geological map and two 1:50,000 coal seam outcrop maps.*

Explanation of Sheet 79. The Geology and Mineral Deposits of the Karibib Area, S. W. Africa. H. F. FROMMURZE, T. W. GEVERS, P. J. ROSSOUW. Pp. 180; figs. 33; pls. 18; map 1. *Abbabis, Damara, Karroo systems and four groups of intrusives represented. Minor deposits of cassiterite, tantalite, lepidolite, beryl, topaz in pegmatites. 18″ × 32″ colored map, scale 1:125,000.*

Publications of the Gold Coast Geological Survey. London, 1946.

Bull. 16. Progress in Geological and Mineral Investigations in the Gold Coast. N. R. JUNNER. Pp. 21; pls. 4; maps 2. *Outline of development history, brief descriptions of deposits. Au, diamonds, Mn, bauxite.*

Memoir 8. The Geology and Hydrology of the Voltaian Basin (Gold Coast Colony). N. R. JUNNER, T. HIRST. Pp. 51; pls. 4.

Memoir 9. Reports on the Bibiani Goldfield. T. HIRST, N. R. JUNNER. Pp. 29; pls. 11; map 1 (colored). *Gold occurs in Precambrian phyllites and volcanics near and in a "porphyry" dike and associated quartz lenses.*

Annales du Service des Mines. Pp. 103; figs. 104; pls. 3; tbl. 1. Comité Spécial du Katanga, Tome XI, 1946. Brussels, 1946.

Geologic Section between Kikosa and Lubudi. Contributions to the Study of the Igneous Rocks and to the Genesis of the Gold Veins of Katanga. Note on Specimens of Basic Rock from the Manono Region, by P. GROSEMANS. **Lithologic Study of the Dolomites of the Upper Roan in Kinsenda No. 23 Drill Hole (Southern Katanga),** by A. JAMOTTE (in French).

Le Service Géologique Régional de Léopoldville, 1940–1946. J. L. D. LEPERSONNE. Pp. 20. Annales de la Soc. Géol. de Belgique Bull. 3. Tervueren, 1946. *Progress report of the Regional Geology Service of Leopoldville, Belgian Congo, 1940–1946.*

Publications of the Department of Scientific and Industrial Research, New Zealand, Wellington, 1945–1946.

Coal at Coal Creek, Centre Hill Survey District, Southland. R. W. WILLETT. Pp. 5; map 1. *Small lens of bituminous in down-faulted block of Tertiary beds.*

Coal Resources of the Kawakawa-Waiomio Area, North Auckland. J. HEALY. Pp. 12; map 1. *No coal yet found by drilling near old mid-Tertiary field exhausted in 1913.*

Wax from Chatham Island Peat. Parts I and II, Geological and Analytical. E. O. MACPHERSON, W. G. HUGHSON. Pp. 44; figs. 9; tbls. 16; maps 6. *Extensive Pleistocene deposits potentially valuable for 9% wax which closely resembles Montan-wax.*

Clays of the Mount Somers District. H. W. WELLMAN, L. R. L. DUNN, I. C. MCDOWALL. Pp. 15; figs. 2. *Residual white-burning clays from Tertiary weathering of early Tertiary rhyolites. Apparently large reserves.*

Clay Deposits near Levin, Waiopehu Survey District. E. O. MACPHERSON, L. R. L. DUNN, I. C. MCDOWALL. Pp. 5; map 1. *"Large quantities" of transported (?) red-burning clay suitable for pipe-manufacture.*

Geology of the Karapiro District, Cambridge. J. HEALY. Pp. 18; figs. 3. *Dam site geology.*

The Ironsands of Fitzroy, New Plymouth. C. OSBORNE HUTTON. Pp. 11; figs. 3; tbls. 3. *Titanomagnetite and tinanhematite from Pleistocene andesite and tuff concentrated by wind, river and tide. Estimate 1,120,000 tons contain 500,000 tons titanomagnetite (8.5% TiO_2).*

Memoir 6. An Outline of Late Cretaceous and Tertiary Diastrophism in New Zealand. E. O. MACPHERSON. Pp. 32; fig. 1; maps 3. *Discordances on structural highs interpreted as showing recurrent orogenies alternating with geosynclinal phases. Possibility of stratigraphic and overlap traps along these highs overlooked in recent unsuccessful oil search.*

Bull. 41 (New Series). The Geology of the Te Kuiti Subdivision (New Zealand). J. MARWICK. Pp. 89; pls. 28; tbls. 7; maps 14. *Structure and physiography, stratigraphy, igneous rocks, economic geology (very minor coal deposits).*

The Reclamation of the Ravine Lands of the Jumma, the United Provinces. H. L. CHHIBBER. Pp. 6; fig. 1. Nat. Geogr. Soc. India Bull. 2. Benares. *Gullying in soft alluvium by torrential seasonal rains working back from rivers. Remedial plan outlined.*

France: Bureau d'Etudes Géologiques et Minières Coloniales. La Chronique des Mines Coloniales (Chronicle of the Colonial Mines).

No. 125. Pp. 38. 1946. *Describes geological and mining activity, economic development, scientific research and legislation of French Colonial Empire during the war and German occupation.*

No. 126. Pp. 31. 1946. *Geological and mining studies in French West Africa and Sahara since 1939.*

No. 127. Pp. 26. 1947. *Geological studies of the different colonies; their mineral production. Extensive bibliography.*

No. 128. Pp. 26. 1947. *Program to modernize and develop more intensively the colonies. Structural geology, petrology and mineralogy of French Indo-china. Activity of non-French Africa during the war. Bibliography.*

No. 129. Pp. 23. 1947. *The search for petroleum in the French Colonies. Regional geology.*

SOCIETY OF ECONOMIC GEOLOGISTS

REPORT OF THE GENERAL COMMITTEE ON RESEARCH OF THE SOCIETY OF ECONOMIC GEOLOGISTS.

At its Annual Business Meeting held in conjunction with the meetings of the Geological Society of America, in Chicago at the end of December, 1945, the Council of the Society of Economic Geologists, then under the Presidency of Dr. O. E. Meinzer, following the recommendations of its Publications Committee whose chairman was Dr. E. S. Moore, authorized the appointment of a Research Committee to further research in economic geology. This committee was duly designated by the President, Dr. W. O. Hotchkiss, and began its work in February 1946. At the next meeting of the Society held jointly with the American Institute of Mining and Metallurgical Engineers in March, 1947, a year after its creation, the Research Committee presented its preliminary results in a series of oral reports which will be published in this and ensuing numbers of "Economic Geology." A word may be permitted here as an introduction to this series of reports.

Organization of the Committee on Research.—It was at once obvious that the Society of Economic Geologists, representing the broad field of applied geology, could not in wisdom confine its research interest entirely to any one phase of applied geology, but should cover broadly all the fields represented. As judged by its membership and publications, these fields include ore deposits, coal, industrial minerals (a more accurate but cumbersome title would be "non-metallics other than fuels"), petroleum, ground water, and engineering geology.

Some of the fields mentioned (such as coal and ore deposits) are well recognized as specialties involving distinctive problems and techniques. Others clearly reach over into related professions. Thus, engineering geology has been well described as "the application of geologic common sense to any sort of engineering problem," and economic geologists dealing with the field of industrial minerals are frequently asked to consider the technology of the product, an aspect reserved in the case of ore deposits to specialists in milling and metallurgy, not to geologists. In such fields as ore deposits, coal, the industrial minerals and even engineering geology, however, related technologic or scientific organizations (such as those for civil engineers, various fuel engineering agencies, the Milling Methods Committee and Industrial Minerals Division of the A. I. M. M. E.) are available in Europe, Canada, the United States, and elsewhere, to serve as clearing houses for the purely technologic, non-geologic work that might otherwise be included under the broader definitions of engineering geology, coal geology, ore geology, or the geology of industrial minerals. In contrast, no purely geological group is available other than the Society of Economic Geologists, to represent *basic geologic* research on the nature, occurrence, and genesis of industrial minerals, coal, and ore deposits, and the Society therefore seems justified in devoting its special attention to these three fields.

As yet there is no other central clearing house in the form of a generally recognized society devoted to the field of engineering geology. The Society of Economic

Geologists seems justified in seeing to it that a research division is available in this field as well, even if it served no other purpose than to bring together those interested in this broad area of interest in case such a group is desirable.

As to petroleum geology and ground water, the American Association of Petroleum Geologists and the Section of Hydrology of the American Geophysical Union are both active agencies furthering basic research on these two fronts of economic geology and both have connections with related international research groups, so that the Society of Economic Geologists would seem to require only a liaison with its two sister organizations, rather than a duplicating committee from its own ranks. In this reasoning it is fully recognized that the American Association of Petroleum Geologists and the American Geophysical Union are more generally oriented toward membership from the U. S. A. both in their names and in their membership; thus, the A. A. P. G. percentage of foreign members is approximately a tenth, while that in the S. E. G. is approximately a third of the total membership. But it was believed far more effective to support "going concerns," especially those here referred to, than to introduce competition between similar organizations, the more so as the corresponding research committees of the two sister organizations, operating under the general chairmanships of Shepard W. Lowman for the A. A. P. G. and Stanley W. Lohman for the A. G. U., were obviously carrying out their work in a most fundamental, imaginative and energetic manner.

In brief, then, it was decided to set up for the six basic fields of research in applied geology as many subcommittees, and to this end a central committee was appointed, as follows:

Coal: Gilbert H. Cady, Illinois State Geological Survey, Urbana, Illinois.
Engineering Geology: Sidney Paige, U. S. War Department Engineers Corps (now with the Joint Research and Development Board, Washington, D. C., U. S. A.).
Ground Water: Oscar E. Meinzer, U. S. Geological Survey, Washington, D. C., U. S. A.
Industrial Minerals: Joseph L. Gillson, Geologist, E. I. Dupont de Nemours Co., Co., Wilmington, Dela., U. S. A.
Ore Deposits: W. D. Johnston, Jr., U. S. Geological Survey, Washington, D. C., U. S. A.
Petroleum and Related Products: Kenneth C. Heald, Vice President, Gulf Oil Corpn., Box 1166, Pittsburgh, Pa., U. S. A.

Chiefly because of their travels, Committee Members O. E. Meinzer, J. L. Gillson, and K. C. Heald requested respectively that:

S. W. Lohman (U. S. Geological Survey, 351 Equitable Building, Denver, Colo., U. S. A.) be appointed to replace Dr. Meinzer, resigned.
R. H. Jahns (Dept. of Geology, Calif. Inst. Techn., Pasadena, Calif., U. S. A.) be appointed as Deputy to Dr. Gillson.
M. Gordon Gulley (Gulf Oil Corpn., Box 1166, Pittsburgh, Pa., U. S. A.) serve as Temporary Deputy to Dr. Heald.

These six committee members, each representing one of the six broad fields of applied geology, were each invited to serve as chairman of a subcommittee dealing with that field and was urged to appoint his own subcommittee with such requisite panels and the like as he might find desirable. In some cases such a sub-committee functioned informally, fluctuating from conference to conference, to insure wider

coverage; in other cases its personnel was limited and specific, as will be indicated in the reports which follow.

Objectives.—The primary motivation for the Research Committee was the consideration that, now that the World War is over, all economic geologists should unite in planning and furthering, each according to the circumstances governing his life, an effective research program. On every side we are hearing of the importance of fundamental research in this broad field. Government surveys and private operators alike complain that new mineral deposits are not being found, that improvements in methods of search are not keeping pace with the needs of the increased consumption resulting from post-war rehabilitation and accelerated industrialization. The discovery of new techniques and of new mineral deposits turns largely on the acquisition and compilation of data in greater quantity and detail; it depends even more, perhaps in view of the new data thus becoming available, upon the correct evaluation of these data with minds free from historical prejudices, upon an interpretation of such new information on a quantitative basis, so as to forecast *a priori* where mineral deposits should and should not be. Fundamental to all such conclusions is a thorough understanding of genesis and localization of the mineral deposits.

As such basic research proceeds on many fronts two things will be necessary. Firstly, as brought out in the early deliberations of the Research Committee—partly through correspondence, partly by conferences in Pittsburgh, New York, Washington, Chicago, and elsewhere—it is essential to know what basic aspects of economic geology are being attacked, how and by whom. Detailed papers will, as hitherto, give the results of specific field and laboratory investigations. But while a subject is under study by a given geologist, there is no assured way in which such a person is informed as to the parallel work of his contemporaries. Some time was spent by the Committee in looking into this aspect of the matter. The workers in several sciences compile yearbooks, carefully designed, with selected authors, who undertake to summarize recent progress is the important subdivisions of their fields and thus to bring to the investigator an up-to-date summary of what is being done in the subject of his interest. Such a volume as The Annual Review of Physiology may serve as an excellent example.

The Committee felt that such a summary, annually prepared, might well serve as a kind of "briefing" in each of the major subdivisions of the six fields of economic geology recognized above. The plan was therefore agreed upon that at least those Subcommittees of the Research Committee as favored this objective would prepare a general statement by the Subcommittee as a whole or by several of its members as could be published in the official organ of the Society.

The second and, in our opinion, equally important task was that of giving thought to the kinds of research which are to be regarded as most timely or most urgent and which should most clearly be undertaken. This procedure is a familiar one in many sciences but has been little practiced among geologists, who appear to prefer leaving it to any individual to "come up with a bright idea" and then to seek whatever subsidies may be available in aid—or not. While there is certainly always danger that regimentation may result from an attempt to advance specific kinds of research, still the time, funds, and individuals available are all so limited that it is an error to wander through the jungle of *possible* subjects for research while certain ones cry out for concerted effort and might well be gladly pursued but for the ignorance of the available investigators.

The several subcommittees have envisaged this problem differently, but all seem to have recognized it. The Subcommittees on Ground Water and Petroleum have now been defining major desirable objectives for over a year, through the American

Geophysical Union and the American Association of Petroleum Geologists, as explained above. The Subcommittee on Engineering Geology is likewise examining its broader objectives. The Subcommittee on Coal has held one meeting and several conferences between individuals and has carried on much correspondence; it has thus been enabled to prepare a statement of its most pressing problems, as given below. The Subcommittee on Ore Deposits has held two general meetings and several conferences with individuals, and has carried on extensive correspondence; all this had yielded a selection of a dozen significant problems and a summary of past accomplishments and especially of *future objectives* in each. This report will appear shortly. The Subcommittee on Industrial Minerals is engaged in questionnairing interested members of the Society who are known to be especially conversant with the geology of the various industrial minerals; a report is scheduled for early publication.

It will be recognized that all such statements have only a qualified value. No committee's judgment as to the future of the science is infallible, nor can a single author claim complete omniscience as to a given facet. Undue influence may thus deflect the stream of research in the wrong direction. There is also the possibility (though it may be overemphasized) that a listing of desirable projects may discourage a particularly thin-skinned investigator from proceeding in a direction that represents his own peculiarly personal choice. When these dangers have been granted, there still remain several patent advantages in the proposed plans.

In the first place, collective thought should certainly be better than that of an individual. The exchange of ideas facilitated by the present plan, both in selecting lines of needed research and in carrying them forward, ought to more than justify any moderate-scale straight-jacketing resulting from a public selection of investigations to be encouraged.

Secondly, the periodic review of what has gone before, especially the reviews which are carried out by several different appraisers in succeeding years, should be informative. Such a review should be most stimulating in placing before research workers, teachers, students, and the like the more promising possibilities to which they can, if not otherwise influenced, devote their efforts most profitably for the common good.

The Council of the Society has placed definite limitations on the Research Committee and its subcommittees. It has agreed that the Committee may not in any of its statements actually sponsor or urge financial support for any projects mentioned, in the name of the Society. The Committee is authorized, however, to recommend or endorse such projects for consideration by others. The Council of the Society has decreed that the Research Committee may not assume financial responsibility in its own name or in that of the Society for any of the projects which it recommends.

The Long Term Plan.—After each Subcommittee has finished and published its report, that report will, it is hoped, be discussed informally between confreres; in print (also informally) in the pages of "Economic Geology" and elsewhere; and in articles specifically prepared to that end. Each Subcommittee, reconstituted from time to time, will issue an annual report in this fashion, successive annual sections on the same subject being written, if desired, by different authors. As the tragic effects of the recent World Conflict pass more and more into limbo, such reviews will become less and less provincial, more and more of world-wide interest and value. Economic geologists engaged in field or laboratory studies anywhere should thus more readily learn what is being done by colleagues elsewhere. Companies (now regrettably still quite tight-lipped) will come more generally to recognize the value of open publication, as petroleum companies in fact already do. Those re-

search workers in the purer aspects of the science will have their horizons broadened, those in the more applied aspects will recognize deeper significances in what they have hitherto seen as only local features. Teachers and students in our schools of geology will find new avenues for their research energies. In a word, the science should, we hope, be stimulated by this plan. At any rate, we propose to try it for two successive years as a worthwhile experiment.

To the Members of the Subcommittees, the general Research Committee extends its sincere thanks. Without the help of many, many thoughtful suggestions the results would not have been brought to the conclusions given below.

CHAS. H. BEHRE, JR.,
Chairman.

REPORT OF THE COMMITTEE ON RESEARCH ON COAL OF THE SOCIETY OF ECONOMIC GEOLOGISTS.

As Chairman of the Subcommittee of Coal Research I respectfully submit the following report of the activities of this Subcommittee from May 1, 1946 to April 30, 1947.

The membership of this Subcommittee consists at the present time of the following individuals:

Paul Averitt	Washington, D. C.	U. S. Geological Survey
Clayton G. Ball	Chicago, Illinois	The Paul Weir Company
G. H. Cady (chm.)	Urbana, Illinois	Illinois Geological Survey
E. C. Dapples	Evanston, Illinois	Northwestern University
C. S. Blair	Birmingham, Ala.	Black Diamond Coal Company
D. J. Fisher	Chicago, Illinois	Chicago, University
R. M. Kosanke	Urbana, Illinois	Illinois Geological Survey
H. Miller	Indianapolis, Indiana	Ayreshire Collieries Corp.
L. C. McCabe	Washington, D. C.	U. S. Bureau of Mines
B. C. Parks	Pittsburgh, Pa.	U. S. Bureau of Mines
T. T. Quirke	Urbana, Illinois	Illinois University
W. Searight	Rolla, Missouri	Missouri Geological Survey
J. M. Schopf	Pittsburgh, Pa.	U. S. Bureau of Mines
W. B. Roe	Chicago, Illinois	Truax Traer Coal Company
C. E. Marshall	Nottingham, England	Nottingham University

Additional representation is desirable for the western and eastern parts of the country and for Canada.

The Subcommittee has met only once and at the single meeting late in December 1946 at Chicago only Averitt, Cady, Dapples, Fisher, Quirke, and Dr. Behre were present. The activities of the Subcommittee have largely been accomplished by correspondence.

At the meeting in December Dr. Behre urged action on the part of the Subcommittee in preparing concrete suggestions in regard to the preferred type of research to be presented to the Committee on Research and the Society at the time of the annual meeting of the Society in March 1947. There was agreement among the members of the Subcommittee that research in the nature of the fundamental constitution of coal was the greatest need. It was left to the chairman of the Subcommittee to prepare a proposal for a project directed toward the objective indicated. It was assumed by the chairman that in setting up such a proposal emphasis would be placed upon geological considerations involved in research in the fundamental constitution of coal.

Pursuant to this assignment a tentative form of a proposal for a major project on coal constitution was prepared and, during February 1947, was circulated among the members of the Subcommittee at that time (Averitt, Ball, Blair, Dapples, Fisher, McCabe, Quirke, Schopf, and Behre). After the receipt of comments and in preparation for the meeting of the Society in March the proposal was revised and shortened. In this form it was presented to the Society March 21, to the Research Committee March 20 and 21, and discussed before the Council of the Society the evening of March 21.

The general features of the project as proposed was described in the outline of the statement made March 21 as follows:

Outline.—This project shall consist of a comprehensive, systematic investigation of coal formation and coal metamorphism, commonly designated "coalification," in the fields of geology, chemistry, and physics. The investigation will involve a study of the nature of the geological conditions effecting coalification, whereby buried vegetable matter is changed to coal and the coal progressively advances in rank, and of the physical, chemical, and thermodynamical considerations involved, and possibly of laboratory demonstration of coal formation and coal metamorphism. The investigation is designed to clarify what is commonly called "the fundamental constitution of coal."

The project will be carried on by a research Chemist and a research Geologist each working independently but in collaboration with the other toward the solution of the problem as a whole. The success of the project depends almost entirely upon the quality of the personnel engaged to carry on the research. They should be untrammeled by restrictive supervision in research procedure and operation. A small number of assistants selected by the research staff may also be required. Some provision will be necessary to take care of special laboratory equipment and field expenses. The project will require housing by some existing research laboratory.

It is anticipated that a period of five years will be adequate to accomplish substantial results.

The cost for the five years, exclusive of the expense of housing contributed by the cooperating laboratory, is estimated as about $150,000, distributed roughly as follows:

Research staff	$ 75,000
Assistants	25,000
Laboratory and field expenses	50,000
	$150,000

It is probable that the value of the housing and services supplied by the cooperating laboratory will represent approximately an equal amount.

In the Proposal of March 21, 1947 the critical considerations were found to be contained in the section entitled Suggestions Concerning Procedure. These paragraphs consisted of an exploration of the nature of the relationship of the Society, as represented by the Council, to the Subcommittee, as to the nature of the sponsorship of proposals for research recommended by the Subcommittees. Obviously this relationship would have to be clarified before the Subcommittee could understand their responsibility and obligations with respect to proposals.

In the discussions that have taken place in the meetings of the parent Research Committee and in the conference of the Research Committee with the Council the matters of special consideration involved the policy to be maintained by the Society

with respect to the extent of responsibility and cooperation of the Society as such in the organization and operation of the various projects that might be proposed. In other words, could the Subcommittees rely upon the prestige, influence, and responsibility of the Society to assist in the organization and operation of the projects? If not upon whose responsibility would such organization and operation rest?

The various conferences and discussions have shown that the Subcommittee overdrew somewhat in their conception of the nature of Society sponsorship. This is a conclusion that may clarify the form of subsequent proposals for research by all Subcommittees. The question resolves itself into one of the policy to be adopted by the Society in the support of research, as to whether it will approve and support with its prestige the assumption of such obligations as its constitution permits as will make possible the effective consummation of a particular program of research recommended by a Subcommittee or will simply stand by and let the Subcommittee operate under its own power.

Up to the present the propriety and merits of the proposal presented by the Coal Research Subcommittee have not been considered. The Subcommittee is convinced that fundamental geological research along the lines suggested are greatly needed to clear up the understanding of facts discovered by the botanist, petrographer, physicist and chemist. Insomuch as coal is a natural deposit the characteristics of which are determined by geological influences, the material should be explored more explicitly than has been the practice, from a geological point of view, with physical, biological, and chemical facts and conditions evaluated and interpreted in accordance with geological facts and conditions. For this reason a proposal is made for a project conducted under geological supervision.

The Subcommittee does not yield in any particular from the conviction that a major project involving investment in personnel, material and operation in the order of $60,000 a year for five years would hasten fundamental discovery by a rate 5 to 10 times as fast as accomplishment is being advanced under present conditions of fundamental research in coal. At the same time, the importance is realized of promoting and stimulating interest in coal geology throughout the country. To this end it is thought desirable to suggest a group of minor projects bearing on the general problem of coal constitution for consideration of those interested in coal research in colleges and universities and research organizations and institutions. The list presented here is tentative and is undergoing consideration and evaluation by the Subcommittee with the expectation that an approved and evaluated list be available within a few weeks.

Projects on Coal Formation (Incoalation).

1. Investigation of the incoalation of the general types of coal material (waxy material, humic material, and fusain) with respect to conditions of coal bed accumulation (might be stated as a study of coal diagenesis).
2. The nature and extent of coal bed compaction during the pre-coal stage to determine the vertical or tangential pressure necessary for incoalation (diagenesis). (Applicable particularly to a study of brown and black lignites.)
3. Bacteria as a possible agent of incoalation.
4. Experimental formation of coal from type coal making materials such as waxes, lignin, and cellulose.
5. Influence of geological environment upon incoalation (type of roof and floor rocks).
6. Nature of the lateral physical alteration from pre-coal to coal (development of blackness, compression, etc.).

7. Fusain and fusinization.
8. Source and occurrence of interstitial colloidal substance in coal particularly in vitrain.
9. Origin of sulphur in coal and effect of variations in adjacent rocks.
10. Nature and causes of the reducing environment accompanying incoalation.

Projects on Coal Metamorphism.

11. Origin, character, and degree of energy applied to coal beds to bring about progressive metamorphism.
12. Study of variations in rank characteristics of the three primary varieties of coal material (waxes, humic matter, fusain).
13. Blackness as an attribute of rank and its cause.
14. Coal luster and reflectivity as a function of rank.
15. The implications of variations in physical attributes of coal upon the molecular structure.
16. Study of coal metamorphism by artificial means starting with lignitic coals of varying types (woody, waxy).
17. Study of coal aromatization as a basis of rank differentiation (chemical condensation).
18. The extent and distribution of colloidal structures in banded coals and the effect upon them of progressive change in rank.
19. Study of the relation between structural irregularity of coal measures and the degree of coal metamorphism in coal fields where this has not been done or on some basis other than carbon ratio.
20. The function of oxygen in coal metamorphism and the structural implications of the loss of oxygen to the chemical compounds.
21. Study of porosity of coal and coal ingredients as a key energy requirement of "coalification."
22. Fundamental nature of anthracitization as evidenced by physical and chemical alterations required.

Energy Studies.

23. Magnitude of the energy required to effect incoalation, bituminous coal metamorphism, and anthracitization.
24. Nature of the chemical changes produced by the geological forces supplied during coalification (possibility of changes in the energy level of the valence electrons during metamorphism).

The Subcommittee will give further consideration to suitable procedure for financing and setting up the proposed major project. It will be necessary to explore the possibilities of assistance that may be obtained without the active sponsorship of the Society. A report on the results of these efforts will be submitted at a later date.

The Subcommittee hopes to be able to function as a clearing house with respect to the types and extent of geological research on coal, fundamental or otherwise, in this country and Canada and the Chairman would be pleased to receive notice in regard to investigations being undertaken or to be undertaken in this field. Many of the members of the committee are actively engaged in coal research and would undoubtedly be glad to contribute suggestions in the fields in which they are individually interested.

G. H. CADY,
Chairman

July 1, 1947.

SCIENTIFIC NOTES AND NEWS

The Rift Club, an informal organization of Southern California professional geologists interested in the study of fault structures, this year visited the Ivanpah district, San Bernardino County, on April 19 and 20. The trip was arranged by the president, Edwin Van Amringe, assistant professor of geology at Pasadena Junior College, and was led by D. Foster Hewett, whose long-awaited monograph on the region is nearing completion.

HERBERT E. WRIGHT, JR., of Brown University, has been appointed Assistant Professor of Geomorphology in the Department of Geology at the University of Minnesota, Minneapolis, Minn. He will take up his new duties in September, 1947.

IRA CRAM of the Pure Oil Company and Past President, American Association of Petroleum Geologists, gave the annual lectures in Petroleum Geology at the University of Michigan on May 1 and May 2.

Hoover, Curtice & Ruby, Inc. and United Engineering Corporation, S. A., announce that Mr. REX TOWNSEND, formerly Assistant Chief of the Petroleum Division of the Department of State, has become a member of their organizations.

GERALD FITZGERALD has been appointed as Chief Topographic Engineer of the U. S. Geological Survey to succeed T. P. PENDLETON who was retired on April first following a prolonged illness.

L. C. GRATON and PROF. BIRCH flew to Iceland on June 22 to investigate the geysers and hot springs there.

The Second International Conference on Soil Mechanics and Foundation Engineering, sponsored by the Netherlands Government, will be held in Rotterdam, Holland, in June 1948, resuming the series initiated at Harvard in 1936 and interrupted by the war. The president of the Conference is Karl Terzaghi, and it is being organized by J. P. Van Bruggen, Director of Public Works, Rotterdam, T. K. Huizinga, Director of the Laboratory of Soil Mechanics in Delft, and other Dutch engineers. The Conference will be conducted in English.

In the United States, a National Committee on Soil Mechanics, consisting of thirty-five outstanding foundation engineers and soil mechanics experts, has been formed with Prof. Philip C. Rutledge of Northwestern University as chairman. Its official address is: U. S. National Committee on Soil Mechanics, the Technological Institute, Northwestern University, Evanston, Illinois. To insure adequate representation of the United States in the technical works of the Conference, the National Committee has been divided into fifteen sub-committees covering the major technical subdivisions of Soil Mechanics and Foundation Engineering.

Prospective members of the Conference and authors of papers are requested to notify the National Committee of their intentions as soon as possible. To meet the conditions set up by the Dutch organizing committee, authors of papers to be published in the first volume of Proceedings of the Conference must submit in triplicate to the National Committee a title and brief (250 word) description of each paper prior to September 1, 1947. For this volume completed papers must be received by the National Committee by December 1, 1947.

Organized travel for those attending the Conference is planned and will be arranged by the National Committee. Complete information on the Conference can be obtained by writing to the U. S. National Committee on Soil Mechanics.

MORRIS M. LEIGHTON, Business Manager of the Economic Geology Publishing Company, and for the past twenty-four years Chief of the State Geological Survey at Urbana, Illinois, was cited by the State University of Iowa, at its centennial commencement exercises on June 7, as a "Distinguished Alumnus," in recognition "of his eminence in his chosen field of Geology and of his contributions to the public welfare."

April 26–29, 1948, are the dates selected for the thirty-third annual meeting of The American Association of Petroleum Geologists, to be held in Denver, Colorado, as announced by Carroll E. Dobbin, president of the Association in Denver.

The Rocky Mountain Association of Geologists is to be the host for the occasion and it is planned that the annual meetings of the Society of Economic Paleontologists and Mineralogists and the Society of Exploration Geophysicists will be held in Denver at the same time.

T. S. Harrison, consulting geologist, has been named general chairman for arrangements and A. E. Brainerd, consulting geologist also of Denver, is assistant general chairman.

M. R. KLEPPER, with the U. S. Geological Survey, has been transferred from Washington, D. C., to Spokane.

JAMES DOUGLAS has been made secretary of Phelps Dodge Corp. and of Phelps Dodge Copper Products Corp.

JOHN D. MCAULIFFE, with Falconbridge Nickel Mines, Falconbridge, Ont., has been promoted from general mine foreman to assistant mine superintendent.

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE
LIBRARY
SEP 9 1947
MANHATTAN
KANSAS